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ILLUMINATING ENGINEERING

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Engineering Department of the Ohio Edison Service Building in Mansfield is lighted by 14 rows of Wakefield 1 x 4 Type 51 Flange Troffers, 14 to a row. The diffuser is #70 Corning.

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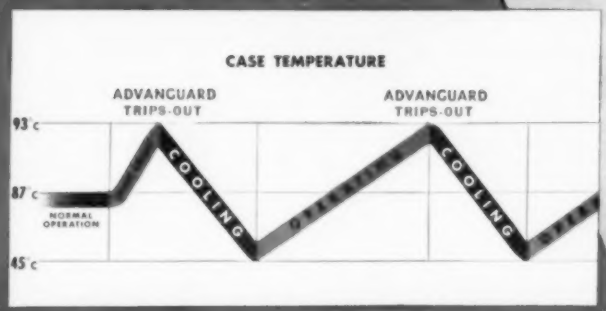

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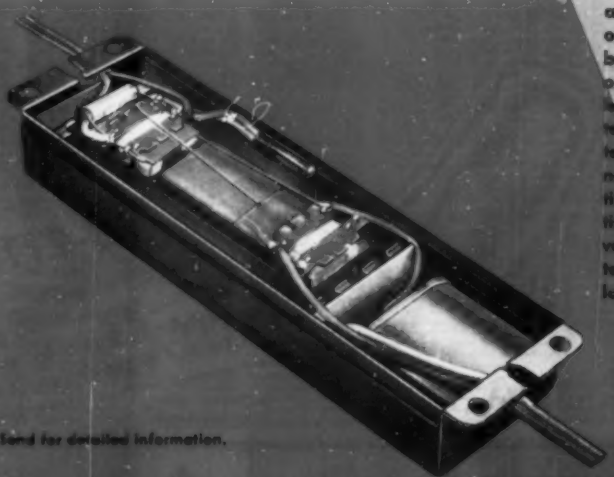

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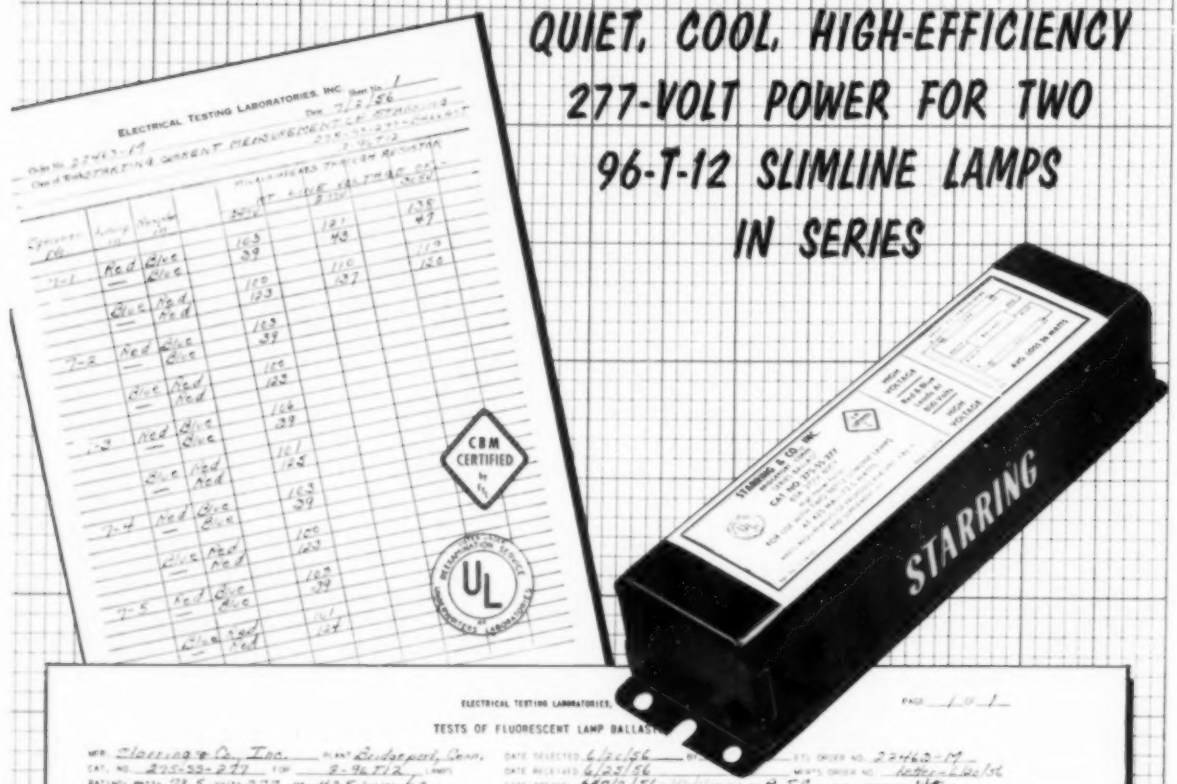

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ILLUMINATING ENGINEERING

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY

February
1958

Vol. LIII, No. 2
In Two Sections
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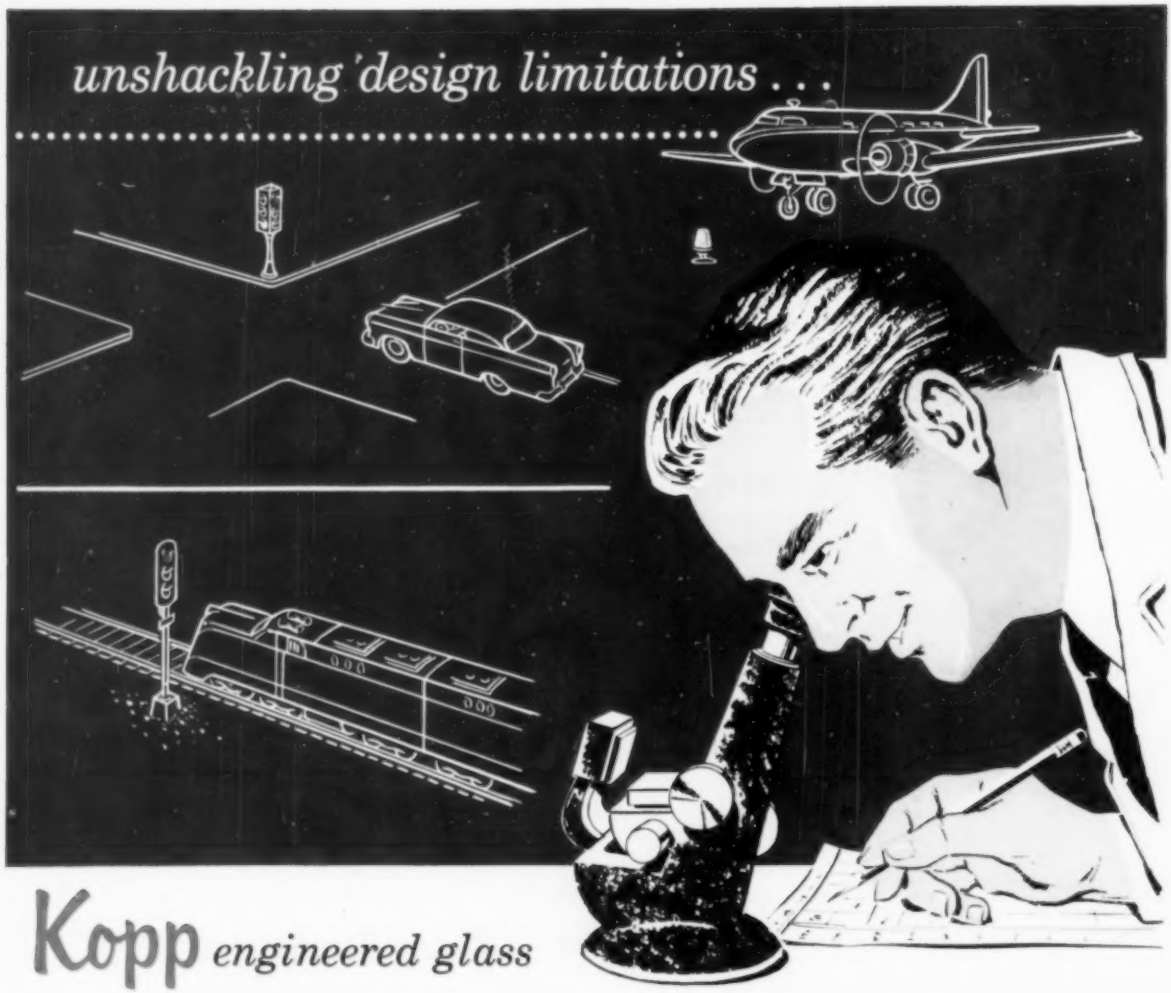

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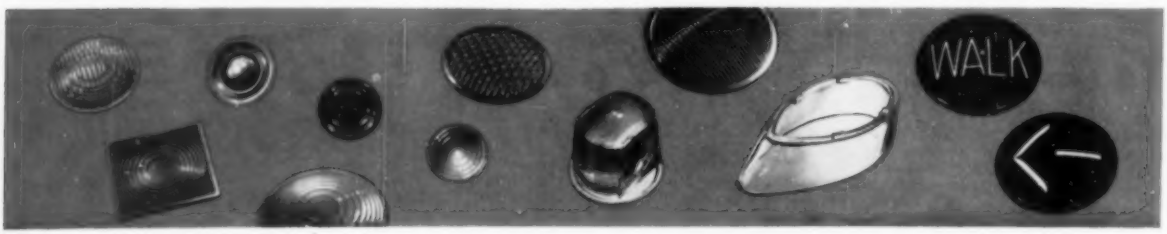
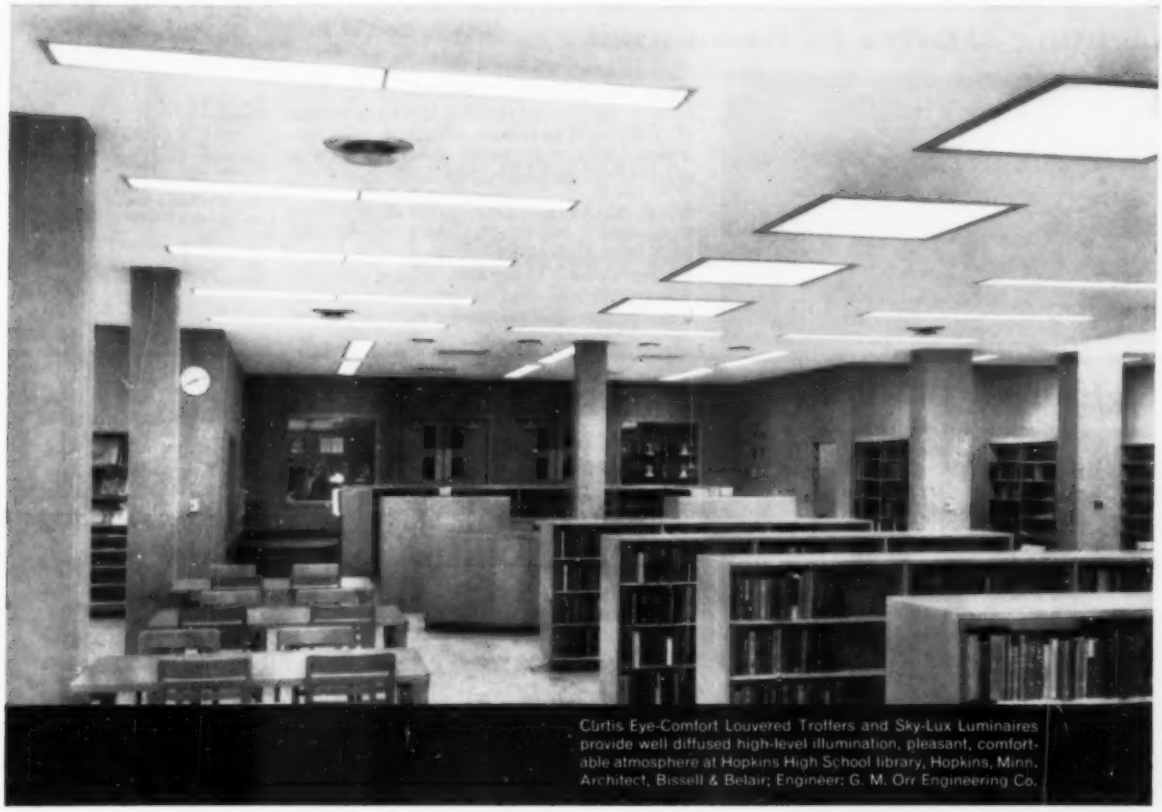


Visioneers...and how they help young minds mature



Curtis Eye-Comfort Louvered Troffers and Sky-Lux Luminaires provide well diffused high-level illumination, pleasant, comfortable atmosphere at Hopkins High School library, Hopkins, Minn. Architect, Bissell & Belair; Engineer: G. M. Orr Engineering Co.

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In the process of learning, young people remember what they *see* much longer than what they hear. Recognizing this fact, school administrators value the importance of providing sufficient light for visual acuity in close classroom work, as well as other activities. Result: an ever-increasing demand for Curtis Planned Lighting Systems. Only natural, because Curtis Visioneers have made detailed and scientific studies of lighting problems inherent to schools. All Curtis school lighting—properly installed—offers uniform level of illumination without objectionable shadows or glare. Curtis Lighting also meets all requirements for *quality illumination . . . low initial cost . . . quick and easy installation . . . minimum maintenance . . . long-run economy*. So, whatever your lighting problem, write today for the name and address of the Curtis Visioneer in the principal city nearest you. Curtis Lighting, Inc., 6135 West 65th St., Chicago 38, Ill. In Canada: 195 Wicksteed Ave., Toronto 17, Canada.

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Visioneers in Planned Lighting

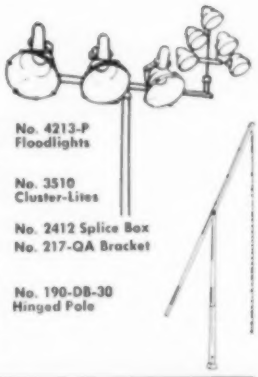
Revere Outdoor Lighting Report

For lighting engineers, lighting planners, and architects interested in outdoor lighting problems and trends

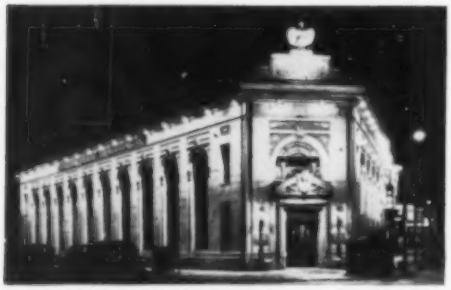
Lighting a Drive-In Restaurant

The Problem: To provide enough light for safe driving and parking of a large volume of traffic; and to provide an attractively illuminated area that readily identifies itself as a drive-in to passing motorists.

The Answer: 3 Revere No. 4213-P floodlights and 5 No. 3510 cluster-lites per pole. Mounting height 33 feet with pole spacing of 24 feet. Cor-ten heavy duty hinged poles No. 199-DB-30 are used to provide convenient maintenance and relamping at ground level.

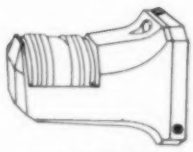


Lighting a Bank Exterior



The Problem: To dramatically highlight the impressive architectural style of the building exterior. Fixtures must be attractive, unobtrusive and placed on the building itself.

The Answer: 36 Revere No. 3151-A lights with 180° prismatic control lens give a ratio of maximum to minimum intensity of approximately 3 to 1. Mounting height is 32 feet with spacing of 8 feet between fixtures. Note even light distribution with absence of "hot spots".

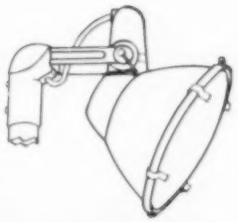


No. 3151-A Light

Lighting a Baseball Field

The Problem: To provide the high level of light necessary for night baseball. Because of the small size of the ball, the speed at which it travels, and the large area of play, baseball demands the greatest intensity of light of all night games.

The Answer: 160 Revere floodlights Nos. 4216-P and 4211-P distributed on 8 poles at 80 feet mounting height. 82 of the lights are No. 4216-P narrow beam with plain lens for concentrating high intensities on the infield and distant mid-field areas. The remainder of the lights (78 No. 4211-P with plain lens) provide a wide beam to illuminate close by zones or the ceiling for fly balls. Combination of wide and narrow beam floodlights provide 20 average footcandles for infield, and 15 average footcandles for outfield.



No. 4216-P Floodlight
No. 4211-P Floodlight

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Class II — Commercial and Industrial — of the "My Most Interesting Lighting Job" Contest takes in a wide variety of installations. The jobs shown here all won first prize in their I.E.S. Section or Chapter MMILJ Contest. They range from a college fieldhouse to a parking garage to a pressroom, and each has its own individual problem the handling of which makes it one of the

Prize Winning Solutions To Lighting Problems

College Fieldhouse

Macalaster College's new $350,000 fieldhouse was designed for a full athletic program, including basketball and indoor practice for football, baseball and track. It is 235 by 122 feet in area with a slanting roof, 36 feet high at the center, built over laminated wood trusses. The floor is dirt, for practice purposes, and the removable basketball court and bleachers are used during that season.

The fieldhouse is also used for exhibitions and large meetings — Macalaster has a student body of 1500 — and the lighting was expected to be adaptable to these several uses.

A uniform level of 20 footcandles over the entire area was deemed satisfactory for those sports using the whole space. By switching this could be reduced to a uniform 10 footcandles for other purposes. In addition, it was felt that 80 footcandles would be necessary over the basketball floor, with a minimum of contrast and glare for players shooting at a basket.

Various types of fluorescent, incandescent and mercury systems were considered, with the decision going to 8-foot rapid start fluorescent. Four 8-foot lamps are used in each fixture around the sides of

During basketball season a wooden court is placed over the dirt floor of the fieldhouse.

the building and 16 in the units over the basketball floor. This provides the lighting levels previously decided upon, 80 footcandles for basketball and 20 for general illumination.

The luminaires are heavily constructed with a wire guard over the bottoms. The unit supplies upward component to reduce brightness contrasts.

This fieldhouse lighting job was the entry of G. B. Moore, of Gausman & Moore, Consulting Engineers, St. Paul, Minn., in the Twin City Section's MMILJ contest. Architects for the building were Bergstedt & Hirsch; electrical contractor, Kehne Electric Co.

Parking Deck

Five requirements were outlined for the lighting system at the City of Sacramento (Calif.) public parking garage decks. The figures in the table attest to its success as to the first two: adequate levels of illumination, and brightnesses and brightness ratios in keeping with good practice. Other requirements were: ruggedness, to withstand shock of car antennas and vibration of vehicular traffic; ability to take all weather conditions of the local climate; and a cost in line with its operation as a city-owned garage. Patrons drive in and park their cars themselves, thus imposing a problem not usually encountered in parking garages.

Measurements Taken at Night
4 Months in operation

Footcandles	Meter — Weston #614 Photronic Footcandles
Between Fixtures	15
Fixture @ Nadir	10
Average (general area)	12.5
Outdoors (for comparison)	.5
Brightness (footlamberts)	Meter — Spectra Brightness Spot Meter Footlamberts
Fixture (bare lamp)	1800
Beams (between fixtures)	7
Driver's visual level (field)	5
Floor	4
Ceiling	3
Ceiling (adjacent to fixture)	40
Outdoors (brightest spot)	2
Brightness Ratios (visual field)	Ratios
Visual level to Outdoors	0.40:1
Visual level to Beams	1.40:1
Floor to Visual level	1.25:1
Beams to Outdoors	0.29:1

Measurements — Average Rainy Day
4 Months in operation

Footcandles	Meter — Weston #614 Photronic Footcandles
Between Fixtures	18
Fixture @ Nadir	12
Average (general area)	15
Outdoors (for comparison)	390
Brightness (footlamberts)	Meter — Spectra Brightness Spot Meter Footlamberts
Fixture (bare lamp)	1800
Beams (between fixtures)	6
Driver's visual level (field)	2
Floor	1
Ceiling	2
Ceiling (adjacent to fixture)	40
Outdoors (brightest spot)	25
Brightness Ratios (visual field)	Ratios
Visual level to Outdoors	12.50:1
Visual level to Beams	3.00:1
Floor to Visual level	2.00:1
Beams to Outdoors	4.15:1

The fixture chosen is of special design, unshielded and about 18 feet in length, with a lamp guard constructed as a flange with a V-type reflector welded to it for positive rigidity. Each unit uses two 800 ma 96-inch T12 rapid start lamps, mounted in tandem with the ballast between.

Installation was the entry of Mel Fenton, Smoot-Holman Co., Sacramento, Calif., in the Mother Lode Chapter's contest for MMILJ.

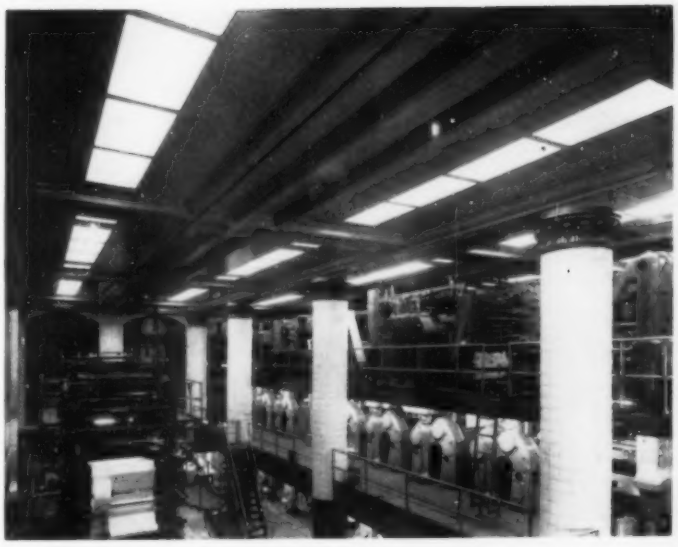
Parking garage, with only half the luminaires lighted.

Newspaper Pressroom

Lighting for the pressroom of the *Spokesman-Review* in Spokane, Wash., presented several rather special problems. One, in particular, was the extremely high ceiling — 35 feet. Another was the difficult maintenance condition caused by ink fog.

To overcome the problem of extreme mounting height, a six-lamp fixture was used. Adequate shielding, without cutting down on the efficiency of the luminaire, was provided by a photolight glass diffusing medium. To satisfy the maintenance conditions, a fixture was designed which provided not only a hinged vapor-tight glass door, but a flange section which would give a vapor-tight seal between the luminaire and the ceiling itself.

This installation was the prize-winner of W. L. Haspedis, Columbia Electric & Manufacturing Co., Spokane, Wash., in the Inland Empire Chapter's MMILJ Contest.



Sales Office

Five areas, lighted with five different makes of equipment, form a demonstration of good office lighting practice in a branch office of a lamp manufacturer. Additional factors considered were that each job has the appearance of being tailored to the area, although the equipment is all stock items readily available from a supply house, and that the average electrician can install it easily.

The general office is 20 by 32 feet in size, with a 9-foot 4-inch ceiling. Around the perimeter, 2 x 4-foot recessed troffers with molded acrylic plastic bottoms each contains three 40-watt rapid start lamps. A luminous element in the center of the room is installed on lay-in grid type troffers set in T-bar supports. Walls are light gray, 60% RF; ceiling, white acoustical plaster, 75% RF; floor, salmon red tile of approximately 20% RF. Brightness of the troffers is 500 footlamberts and illumi-

General Office

Manager's Office

Conference Room

Private Office

nation level after four months is 120 footcandles under the center element.

The manager's office is 14 feet square and has a complete luminous ceiling of vinyl plastic in 3-foot square units set in V-channels suspended 18 inches from the single-lamp 74-watt and 55-watt reflector strips. Strips are on 18-inch centers. The plenum is painted white and the ballasts are remotely located. Brightness of the ceiling is 200 footlamberts with lighting level of 100 footcandles. Walls are green and wall-to-wall carpeting is light gray-green.

A secretary's office (not shown) is treated in the same manner as the manager's from the standpoint of colors. Lighting here is from surface-mounted fixtures and a valance over an inside window.

In the 13- x 20-foot conference room are two six-lamp 40-watt recessed units, 4 x 4-feet in size, with acrylic plastic arched diffusers, and eight two-lamp 40-watt recessed louvered low-brightness troffers with parabolic Alzak reflectors. Illumination is 80 footcandles; brightness of troffers, 150 footlamberts transversely and 350 longitudinally; that of square fixtures is 450 footlamberts. Surfaces are the same as in the general office.

In a private office, 200-watt silvered bowl recessed louvered incandescent units and a two-lamp continuous fluorescent cove supply 70 footcandles. The cove is mounted 18 inches below the ceiling and uses one strip of deluxe warm white lamps and one strip of daylight, separately switched. The area has light gray walls, light green tile floor and white acoustical ceiling. Maximum ceiling brightness, immediately above the cove, is 200 footlamberts; that of the recessed fixtures is 350.

This five-part lighting installation won first prize in the Maryland Section as the MMILJ entry of H. M. White, Baltimore Gas & Electric Co.

Office — Demonstration Room

Used not only for usual office tasks, but also for demonstration purposes, the lighting in the office of these equipment manufacturers' representatives is composed of many varieties. Luminous indirect lighting in a modular fixture supplies a general illumination of 100 footcandles. Other office lighting equipment shown includes concentric ring units and flush recessed round and square silvered bowl units.

Store and display equipment includes luminous indirect or louvered direct-indirect high-output fluorescent fixtures, direct incandescent, a combination indirect lighting unit with a built-in downlight for accenting displays, flush-mounted spots and adjustable gimbal mounted eyeball units, pendent fixtures in silver, gold, black or combinations of these colors, and a daylight blue reflector for lighting diamond displays.

Decorative lighting elements are also shown: cove and valance lighting wall-mounted brackets and interchangeable colored anodized aluminum reflectors are included in this classification.

Partitions are of Philippine mahogany and other walls are painted pastel green. The tile floors are of a light-reflecting harmonizing color and the ceiling is of a suspended Fiberglas acoustical tile, squares of which can be easily removed.

A large framed multiple photograph, featuring Mt. Rainier, is displayed by spot lights from across the room.

This installation was the first-prize winning entry in the Puget Sound Section, of B. T. Heinz and Freeman C. Scharr, of Seattle, Wash., manufacturers' representatives, whose office it is. This entry also won first place at the Pacific Northwest Regional contest.

Home and Automobile Supply Store

A leaky roof, disinclined to permanent repair, added an unusual problem to the remodeling of the L. E. Davis Firestone Store, St. Joseph, Mo. A lighting system was desired that would de-emphasize the ceiling, particularly through the center of the building. The owner also wanted a maximum of highlighting on the merchandise, which is mostly hard goods, and a minimum level in the aisles. He feels that this tends to focus attention on the wares.

Long boxes, about 12 inches deep and 6 feet wide were constructed on the ceiling over the merchandising areas. Recessed louvered cans on 4-foot centers, using 150-watt R40 spots, were mounted in the boxes. These units provide about 100 footcandles on the merchandise. The same type fixtures are used on three sides of the perimeter of the store,

and in window areas 150-watt PAR38 spots supply approximately 200 footcandles.

At the rear of the store the ceiling was lowered three feet, projecting outward from the rear wall about 4 feet. On the lower forward edge of this construction a valance was installed, with a total of 58 four-foot two-lamp fluorescent strip.

In addition to automobile accessories and appliances, the owner has added drugs, soft goods, sporting equipment and a lunch counter. The latter area is lighted by recessed square fixtures with opal glass diffusers, using 100-watt incandescent lamps.

The boxes mounted on the ceiling are painted a flat white and the ceiling areas between are of a darker color with reflectance of 10 per cent, which aids in concealing stains from the leaky roof. Walls are of pastel shades, 50 per cent reflectance, and the floor is about 15 per cent.

This installation was the prize-winning entry of E. J. Cook, St. Joseph Light and Power Co., St. Joseph, Mo., in the Heart of America Section's contest for My Most Interesting Lighting Job.

Auto Showroom

Young's Pontiac, in Coos Bay, Ore., is in a highly competitive business at a location which needed help in attracting attention. Foot traffic is limited at the intersection, and automobile traffic medium. The "L"-shaped showroom needed lighting to stop traffic. The three-part system installed has achieved this with outstanding success.

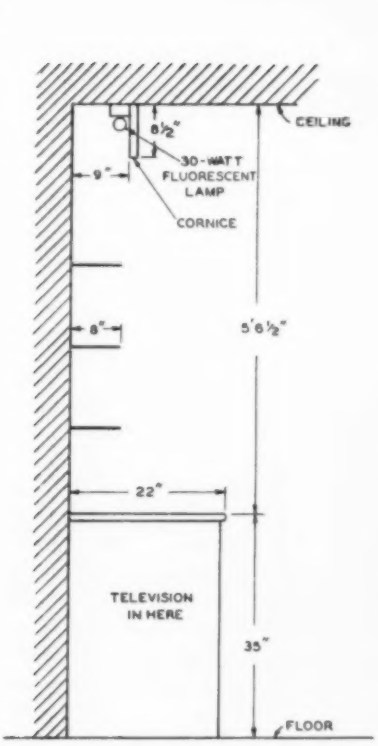
To the high-level general illumination has been added a unique system of color lighting which may be used in many combinations to harmonize with the cars on display. This color accent is from twenty adjustable bullet-type reflector spots, spaced 48 inches apart around the glass front of the showroom. Used in them are twenty 150-watt R40 spot lamps: five white, five red, four yellow, three green and three blue. The units are wired to four branch circuits and may be switched to enable numerous pleasing combinations of color lighting to emphasize the color dynamics intended by the automobile designers.

General illumination is provided by two sets of recessed vinyl luminous area fixtures. Eight units light the long upper part of the "L," and four make up the shorter set. Each fixture has four 48-inch T12 40-watt standard cool white rapid start lamps, providing 80 footcandles maintained.

Between these two sets of luminaires, at the turning section of the "L," eight 300-watt incandescent units with prismatic lenses are recessed in an elliptical pattern, spaced approximately 36 inches apart. They also provide 80 footcandles maintained.

Showroom color scheme is: light sand tone plaster ceiling, 72% RF; light green lower wall of texturized Douglas fir plywood, 60% RF; tan and brown asphalt tile floor, averaging 60% RF. The traditional Pontiac neon sign over the entrance easily identifies the salesroom without distracting from the basic lighting effect.

Installation was designed by Donald C. Statham, Pacific Power & Light Co., Coos Bay, Ore., and won first prize in the Oregon Section of I.E.S.



INSTALLATION A AT CINCINNATI, OHIO

Lighting Glass Shelves

LIGHTING OBJECTIVE: To illuminate objets d'art displayed in niches with glass shelves.

GENERAL INFORMATION: Display niche recesses in homes are usually quite dark and, therefore, often ineffective unless lighting is built in. The recesses in Installation A are 36 inches wide and 8 inches deep. The back and side walls of the niches are painted a light apple green (50% RF).*

In Installation B, the niche recesses are 25 inches wide and 9½ inches deep. The back and side walls are painted white (80% RF).*

INSTALLATION: The cross section of one of the glass shelf niches of installation A, shows a 30-watt cool white deluxe fluorescent lamp and channel installed across the top. The shelves are not crowded with opaque objects, so that satisfactory results are obtained with the lighting installed across the top. The brightness of the back wall varies from 34 footlamberts just below the shielding cornice board to about 5 footlamberts midway between the lowest glass shelf and the wooden counter at the bottom.

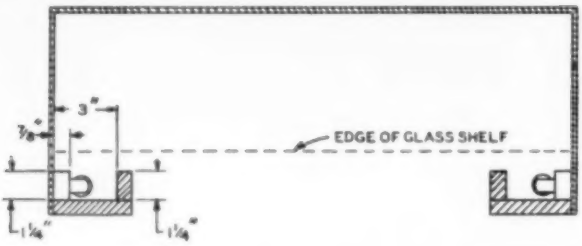
The lavabo planter hung on the wall between the two niches in installation A, is lighted by a Century #1672 Project-o-lite recessed in the 8½-foot ceiling 48 inches out from the wall area it illuminates. This unit employs a 250-watt G-30 spot light lamp with C-5 filament. The pattern of light on the wall is obtained by adjusting two pairs of small baffles within the unit.

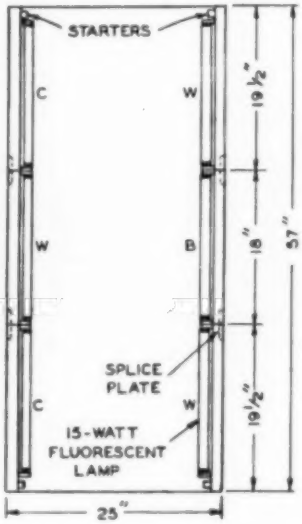
*The back and side walls of niches should be painted a light color.

(over)

A.I.A. File No. 31-J

INSTALLATION B
AT MACEDONIA, OHIO





C = COOL WHITE DELUXE LAMP
W = WARM WHITE DELUXE LAMP
B = BLUE FLUORESCENT LAMP

The plan view of one of the shelves in Installation B showing the position of 15-watt fluorescent lamps mounted vertically at the front and down the sides of the niches. The channels were cut to the minimum lengths, and assembled into continuous strips with small splice plates and screws. Starters for the two center lamps on each side and all the ballasts are located in the enclosed cupboards beneath the open shelves. No undesirable dark streak is present, down the center of the shelf area, as is present if the shelf area is too wide. The brightness of the niche back wall varies from 120 to 180 footlamberts at the corners and from 60 to 90 footlamberts in the center. The use of warm white and cool white lamps in adjacent positions gives the impression of pale pink and pale blue light on the white paint; the one blue fluorescent lamp in each niche serves as a focal point of color.

The coffee table in this living room is highlighted by a 150-watt projector spot lamp in a louvered luminaire recessed in the ceiling.

Lighting data for Installation A submitted by Ruth Rutterer, Cincinnati Gas and Electric Co., and for Installation B, by Aileen Page, General Electric Co., Cleveland, as illustrations of alternate solutions to a lighting problem and to aid in the design of similar installations.

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A new look at the . . .

Measurement of Light and Color

By DEANE B. JUDD

Since 1935 the standard definition of light has been based on a luminous-efficiency function first adopted provisionally by the International Commission on Illumination (CIE) in 1924. This function was intended to give the reciprocal of the spectral radiance required to make each part of the spectrum appear equally bright to the average normal eye, and new determinations during the last 30 years indicate that the standard luminous-efficiency function succeeds very well in doing this, except perhaps that it may be too low in the short-wave portion (less than 460 mμ). At the 1955 Congress of the CIE in Zürich, Dr. W. S. Stiles presented preliminary results of determinations of the color-mixture functions that suggested an entirely new basis for the definition of light. To make clear this new basis, and the advantages that it may have, the basic principles of the measurement of light and color are examined briefly.

Measurement of Light

BASIC PROBLEM in the measurement of light is to determine how many units of light are emitted by an unknown source even though this source has a color quality, or chromaticity, different from that of the standard of light with which it must be compared. Sometimes this problem is called the problem of heterochromatic photometry. Heterochromatic photometry has been carried out in three ways; one is by direct visual comparison, the so-called equality-of-brightness method; another is to apply the equality-of-brightness method in succession to a series of lights of intermediate chromaticities, called the cascade or step-by-step method; and the third is to present the two lights to be compared alternately in the same photometric field with a frequency of about five alterations per second, the so-called flicker method.

The first method, that is, by direct visual comparison, is the most direct and fundamental. The observer sees the two lights to be compared, side by side, filling the two halves of a photometer field. He must adjust the radiant flux of the comparison field until the two halves of the photometer field appear to him equally bright. This method is also the most difficult. If, as is usual, the standard is light from an incandescent lamp, and the light to be evaluated is, for example, the orange-red light from a neon lamp, there may be a range by a factor of two or more, within which the observer cannot decide which half of the field is the brighter. The larger the chromaticity difference between the test side of the field and the standard side, the greater is the range of uncertainty.

The second, or cascade method, substitutes a series of less difficult comparisons for the single direct comparison. Each step of the cascade method is less difficult because the chromaticity differences between the two sides of the photometer field is smaller.

In the third, or flicker method, the observer adjusts the radiant flux of the comparison field until the perception of flicker is a minimum. The reason why this adjustment is supposed to correspond to equal brightness of the two lights, is that the perception of chromaticness requires more time to develop in the visual mechanism of the observer than is required for perceiving brightness. The speed of alternation is set so as to eliminate, or nearly eliminate, any flicker caused by a chromaticity difference between the two lights, and then an adjustment for a minimum of flicker is supposed to correspond to the condition that the luminous flux of the one light is the same as that from the other.

These three methods of comparing an unknown light with a standard of light unfortunately yield rather discordant results. They all depend importantly on the angular size of the photometric field, and indeed this might be expected because the spectral sensitivity of the human eye is simply the average of the receptors (rods and cones) of the portion stimulated, and it is known histologically

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(from the work of Polyak, 1941, for example) that the proportion of rods increases from zero at the fovea centralis to ever higher fractions as the periphery of the retina is approached. Since the rods have their maximum sensitivity at about 510 mμ, and the cones at about 560 mμ, it is plain that a different appraisal of radiant flux may be obtained from a small field than from a large. Furthermore, the central three or four degrees of the normal human retina is covered with an irregular spot of yellow pigment, the macular pigment, and this too would lead us to expect a different appraisal from a field of large angular extent than from a small one.

These three methods likewise depend differently on the magnitude of the areal density of radiant flux coming per unit solid angle from the photometric fields. If this radiant flux density, or radiance, is sufficiently high, the retinal rods reach a maximum in their response (as shown by Aguilar and Stiles, 1953), while the retinal cones give increasing responses even though the radiance be increased by a thousand fold beyond this amount. The change in eye sensitivity from that of the cones at high radiance to that of the rods at low, has been known since 1825 as the Purkinje effect. Photometry by the direct-comparison method, or by the cascade method, is greatly influenced by the Purkinje effect. Photometry by the flicker method also depends on the radiance of the photometric field, but the direction of change is opposite. For want of a better name, this dependence is called the inverse Purkinje effect. The existence of an inverse Purkinje effect in flicker photometry makes us wonder whether flicker photometry really measures the same aspect of radiant flux as is measured by equality-of-brightness photometry. The fact is that we know relatively little about what goes on in the visual mechanism during a setting by flicker photometry except that the phenomena must be very complicated.

If the field size be kept small, say less than two degrees, the radiance be kept high, and the photometric fields be surrounded by a bright field, the participation of the rods is minimized, and the three methods of heterochromatic photometry yield results that are much less discordant. The early years of the International Commission on Illumination were spent in trying to define a standard photometric procedures along these lines that could be used by all countries in setting up and administering their standards of light, but no satisfactory method could be developed.

The requirements that a satisfactory definition of light must meet are:

1. Equal amounts of light by this definition must appear equally bright under the standard observing conditions of field size and of photometric brightness of field and surrounding field.

2. The amount of light from two or more sources shall be the sum of the amounts from the separate sources.

The first requirement points toward the equality-of-brightness method, or at least toward the cascade method. In so far as the flicker method disagrees under the standard observing conditions with these more fundamental methods, the flicker method cannot form the basis of a satisfactory definition of light.

The second requirement, that the photometric scale be additive, is imposed because a nonadditive definition of light is judged to be too complicated to be of any practical use in industry. (The inverse-square law, for example, would not apply to light.) Unfortunately, the evaluation of radiant flux by our eyes is not always as simple as this. If the two lights, standard and test, have the same chromaticities, even though they may be spectrally very different, the photometric scale by direct visual comparison is strictly additive. The more complicated facts of heterochromatic photometry may be best described in terms of an actual experiment.

If one half of a photometric field be filled with one unit of light from the standard source of incandescent-lamp light of color temperature 2042°K, and enough red light be introduced into the other half of the field to make the two half-fields appear equally bright, by requirement (1) this amount of red light must also be one unit.

Secondly, if green light be substituted for the red in the comparison half of the photometric field, similarly there may be found one unit of green light.

Thirdly, if now the one unit of red light and the one unit of green light both be introduced simultaneously into the comparison field, this mixture ought to appear as bright as two units of the standard light, if the second requirement, additivity, is to be fulfilled. Experimentally, however, the mixture of the red and green lights usually appears darker than the two units of the standard incandescent light. In order to obtain the appearance of equal brightness it is necessary to reduce the amount of light from the standard source by amounts ranging from 0 to 50 per cent. This type of failure of additivity was first noticed by Helmholtz and has been studied in detail by Kohlrausch (1923, 1937). The effect has often been called the Helmholtz-Kohlrausch effect since J. Urbanek and E. Ferencz (1939) gave it that brief name in their brilliant and complete analysis of visual hetero-

chromatic photometry. It is discussed by H. König (1947) in his detailed analysis of the concept of brightness under the name "Farbenglut."

To be sure, the setting for one unit of red light, and that for one unit of green light, is uncertain by about a factor of two. (The third setting, that between the standard incandescent-lamp light and the mixture of one unit of red light with one unit of green light, is, of course, much more certain because the chromaticity difference is much smaller.) The Helmholtz-Kohlrausch effect is thus not certainly demonstrable by a single trial at these three operations, but has statistical meaning only. Nevertheless it is not possible to devise a definition of light that meets both requirements strictly. If the definition includes strict additivity, it must imply failure by at least 25 per cent in some cases to have equal amounts of light appear equally bright.

On the other hand, if the comparison be made by flicker photometry, the Helmholtz-Kohlrausch effect, though not completely absent, is much smaller (Jaggi, 1939; Dresler, 1938). This experimental fact suggests basing a definition of light on flicker photometry.

The Helmholtz-Kohlrausch effect corresponds roughly to the theoretical idea that most of our brightness perception results directly from receptors in the retina that serve this purpose only, but some of it is associated with the red-sensing and green-sensing mechanisms. Thus, when the red and green lights are mixed and the redness and greenness cancel to produce yellow, some of the brightness perception is lost. This theoretical idea is supported by the fact that deuteranomalous observers, who have an ability to discriminate red from green much less than that possessed by observers of normal vision, show almost no Helmholtz-Kohlrausch effect (Kohlrausch, 1937). This experimental fact has led to the rather paradoxical proposal that a definition of light be based on equality-of-brightness photometry by deuteranomalous observers.

The question of defining light in a practically useful way has been argued at great length in the International Commission on Illumination ever since its formation early in this century. In 1935 they resolved the dilemma by rejecting all three methods of heterochromatic photometry, and substituting for them the idea of luminous efficiency. Each sample of radiant flux is said to be associated with a fixed amount of luminous flux, the ratio between the two being luminous efficiency in lumens per watt. Luminous efficiency is taken to be solely a function of the wavelength composition of the radiant flux, the particular function being defined by adopting values for the relative luminous efficiencies of each part of the visible spectrum, these values having been adopted provisionally by the CIE in 1924. This definition of light was reaffirmed (CIE, 1939) as follows:

"Every result of photometric measurement shall be placed on the unique fundamental base defined by the relation:

$$B = K_m \int E_\lambda V_\lambda d\lambda \qquad (1)$$

where B means luminous brightness (now called luminance), K_m the maximum coefficient of visibility (now called maximum luminous efficiency), E_λ the spectral radiances per unit wavelength, V_λ the relative visibility factors (now called relative luminous efficiencies) defined by the CIE, λ the wavelength."

It is evident that if every photometric measurement is placed on this base, the photometric scale used will be strictly additive, for additivity is written into the definition itself. It may not be too clear, however, how to place every photometric measurement on this base unless each source is measured spectroradiometrically to determine its spectral radiance as a function of wavelength, E_λ, and then luminance, B, is computed directly by the defining equation (1). This fundamental method is too time-consuming, and too beset with difficulty, to be used except occasionally. The practical method recommended in assigning a number of candelas to specify the luminous intensity of an unknown source is the so-called filter method. A filter is selected which may be applied to the standard source to produce a close chromaticity match for the unknown source. The spectral transmittance of this filter as a function of wavelength is then determined with a spectrophotometer. The transmittance of the filter for the standard light source whose spectral composition is known is then computed by means of the above specified relative spectral luminous efficiencies. Then the comparison is made by direct visual comparison in a two-degree field of adequate luminance. If a reasonably close duplication in spectral composition is attainable, but not a sufficiently close duplication of chromaticity, the flicker method is recommended. The result of either method takes into account the influence of the filter by using the transmittance found for it by computation.

We may summarize the definition of light, which has lived now for 20 years, by saying that it is technically convenient because it makes light an additive quantity by definition, but does not conform strictly to the first requirement that equal amounts of light shall appear equally bright in all cases. The curve of spectral luminous efficiency has been chosen as an average of determinations by the

cascade and flicker methods so that equal amounts of light from whatever two parts of the spectrum appear equally bright to the average observer, and, of course, it was the intention so to define light that this requirement should be met as closely as possible for light sources of mixed wavelength composition as well. Because of this intention, luminous flux has been officially defined as the characteristic of radiant flux which expresses its capacity to produce a luminous sensation as evaluated from the standard spectral luminous efficiencies. This has been an official attempt to eat the cake and have it too, that is, to claim to have satisfied the two basic requirements which we have seen cannot both be satisfied simultaneously. At the Zürich meeting of the CIE in 1955, it was proposed to drop from the definition of luminous flux the phrase, *in accord with its ability to produce luminous sensation.* This proposal recognizes the facts of life. It is not enough to intend to evaluate radiant flux in accord with luminous sensation; the fact is that the definition given fails to do so, as must also any definition that makes light an additive quantity. We have therefore the definition of a technical quantity that is practically useful because it satisfies the second requirement perfectly and the first requirement approximately. It is, however, not the only definition that does this, and to see how another proposal has arisen for a still less contradictory definition of light, we must introduce a new subject, the measurement of color.

Measurement of Color

Measurement of color is based on the experimental fact well known in the time of Thomas Young (1805) that it is possible to produce nearly every color by a mixture of lights of but three colors, red, green, and blue. First set up a spotlight (say incandescent lamp light) to shine on a white screen. This appears to us as a bright spot having a reddish yellow color of low saturation. Then let a neighboring spot on the screen be illuminated simultaneously by light from three lamps, one red, one green, and the other blue. The radiant flux entering the eye of the observer is the sum of the separate fluxes that would enter the eye from each lamp separately if the other two were turned off. The observer sees the second spot as red, green, blue, or some intermediate color depending on the relative amounts of radiant flux received from the red, green, and blue lights. By varying these amounts we discover in general that we can produce almost any other color. For example, by mixing red light with green light we can produce yellow colors; by mixing red light with blue light we can produce purple colors; and from blue and green lights, cyan colors. In particular, we discover that we can produce by mixture of much red, nearly as much green, and a small amount of blue, an exact match for the color of the first spotlight, incandescent-lamp light. By giving the amounts of red, green, and blue light required for the color match, known as tristimulus values, this light can be specified, and we can say that we have measured its color.

The colors that cannot be produced by such a three-light mixture are those that appear more saturated than any of these mixtures, for example, the colors of the pure spectrum. Even if we choose our primary red, green, and blue lights directly from the spectrum, it is still found that not all of the other spectrum colors can be produced by mixture of any one triad of primary colors. But even these colors can be specified by tristimulus values. It is necessary only to add to the light to be specified some of the primary differing most from it, thus reducing its purity so that the mixture can be matched by some combination of the other two primaries. For example, let the color to be specified be that of the spectrum at about 490 mμ, which is seen as a saturated color of bluegreen hue. By mixing the blue and green primaries in the correct proportion we can produce a mixture of this bluegreen hue, but by comparison with the pure spectrum color, this mixture appears grayish, or less saturated. Then we add a sufficient amount of the red primary to the light (490 mμ), whose color is to be specified, to produce a match to some proportion of the blue and green primaries. In this way, the spectrum color (490 mμ) has been specified in terms of the three primaries, red, green, and blue. As before, these amounts are said to be the tristimulus values of the color to be specified except that the amount of the primary (red) added to the test color is recorded with a negative algebraic sign. The specification might be $R = -20$; $G = 60$; $B = 60$.

The usual theoretical interpretation of this finding that no selection of three primary lights can be found whose combination in positive amounts produces all other colors is that there exist three light-sensitive substances in the normal retina whose spectral sensitivities overlap. That is, nearly all parts of the visible spectrum serve to excite more than one of the three independent receptor systems comprising the visual mechanism. Conversely, if it were possible to find parts of the spectrum that yield excitation of each receptor system to the exclusion of the other two, then, and only then, could we expect to duplicate all colors with mixtures of these three spectrum lights.

Usefulness of the method of color measurement by means of tristimulus values is limited first by

the fact that the choice of red, green, and blue lights to be used as primaries is arbitrary and has still to be standardized, and second its usefulness is limited by the fact that another observer, even though also possessing normal color vision, would find somewhat different tristimulus values for the same test color; so the observer, too, has to be standardized. Finally we would like to know what amounts of any three specified primaries would be required by an average observer to match this same test color. The basis for transferring tristimulus values from one set of primaries to another can be discovered by experiments with the simple apparatus just described. To summarize the results of these experiments it is hard to do better than to take the summary written out by Grassmann (1853), now known as Grassmann's laws:

1. The eye can distinguish only three kinds of color differences or variations (expressible as variations in dominant wavelength, luminance, and purity.

2. If, of a two-component mixture, one component is steadily changed (while the other remains constant), the color of the mixture steadily changes.

3. Lights of the same color (that is, the same dominant wavelength, same luminance, and same purity, or alternatively, the same tristimulus values) produce identical effects in mixtures regardless of their spectral composition.

All modern colorimetry is based upon the principle stated in the third Grassmann law. It means that we can deal with lights on the basis of their colors alone, without regard for their spectral composition. It generates the following important corollaries:

3a. Two lights of the same color, added to two other lights of the same color, produce mixtures that likewise have the same color; or stated in terms of tristimulus values, if X_1, Y_1, Z_1 are the amounts of red, green, and blue light required to match one light, and X_2, Y_2, Z_2 are the amounts for a second light, then the tristimulus values for the color produced by adding these two lights together are simply: $X_1 + X_2$; $Y_1 + Y_2$; $Z_1 + Z_2$.

3b. Two lights of the same color, each subtracted respectively from mixtures of equal color, leave remainders that color match. This corollary justifies the use of a negative tristimulus value to specify colors outside the gamut of the three primaries chosen.

3c. If one unit of one light has the same color as one unit of another light, any number of units (or fraction of a unit) of the one light has the same color as the same number of units (or same fraction of a unit) of the other. That is, increasing or decreasing by any factor the radiance of two lights of the same color, even though of different spectral compositions, will not destroy the color match.

Grassmann's laws have been subjected to repeated experimental tests (Blottiau, 1947; Trezona, 1953, 1954; Stiles, 1955), and no certain failures of these laws have been established for observation within a large middle range of luminance (about 1 to 1000 millilamberts) by using observing fields of small angular extent (those subtending 2 degrees or less). For fields less bright than one millilambert, departures from Grassmann's laws have been found that seem to be ascribable to the intrusion of rod vision. Wright (1936) also has shown that the color match might break down if the radiance of the fields be increased unduly. Such a breakdown may occur at luminances greater than 1000 millilamberts.

Grassmann's laws permit us to specify color by means of three additive scales, a red, a green, and a blue. They do more. Every light may be specified physically by the spectral composition of its radiant flux. If we knew for any observer the tristimulus values of unit radiant flux for each part of the spectrum, we could by Grassmann's law (3c) compute how much red, green, and blue is required to match each part of the spectrum of any known light, then by Grassmann's law (3a) we find simply by adding up these amounts for the whole spectrum a prediction of the tristimulus values that would be found by that observer for the light itself. To set up a standard observer and colorimetric coordinate system it is necessary, first to decide on some set of primary colors to be taken as standard, second to decide on the units by which to express the amounts of these primaries, and third to evaluate in these units for the average, normal eye, the tristimulus values of each part of the visible spectrum.

The 1931 CIE Standard Observer And Coordinate System for Colorimetry

In 1931 the International Commission on Illumination (CIE) recommended a standard system of the kind just described for international use in the measurement of color.

1. *Choice of primaries.* In order to permit the tristimulus values of the spectrum to be specified by a number not less than zero, three imaginary primaries were chosen, a blue theoretically more pure than any spectrum blue, a green theoretically more pure than any spectrum green, and a purplish red theoretically more pure than any producible by mixing spectrum red with spectrum violet. These primaries are imaginary in the sense that energy distributions corresponding to them must have negative values for some parts of the spectrum; but in terms of the facts of color-mixture summarized

by Grassmann's laws they are just as meaningful as primaries corresponding to real lights, that is, lights definable by energy distributions nowhere in the spectrum less than zero.

2. *Choice of units.* Arbitrary units were chosen for the scales on which the amounts of these primaries are expressed such that equal amounts correspond to the chromaticity of the so-called equal energy source, that is, a source such that the amount of energy between any two wavelength limits is proportional to the wavelength difference between the limits.

3. *Choice of standard tristimulus values of the* spectrum. Since no direct determinations of the tristimulus values of the equal-energy spectrum had been made at that time, the standard tristimulus values were deduced from measurements of spectrum chromaticities, x_λ, y_λ, z_λ, by 17 British observers (10 studied by Wright, 1928-1929; 7 by Guild, 1931) combined with the standard luminous-efficiency function, V_λ, at that time already adopted provisionally. The derivation of standard tristimulus values of the spectrum was such that these values, $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$ satisfied the two conditions (2 and 3):

$$\begin{aligned} \bar{x}_\lambda / (\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda) &= x_\lambda \\ \bar{y}_\lambda / (\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda) &= y_\lambda \\ \bar{z}_\lambda / (\bar{x}_\lambda + \bar{y}_\lambda + \bar{z}_\lambda) &= z_\lambda \end{aligned} \qquad (2)$$

$$\bar{x}_\lambda L_x + \bar{y}_\lambda L_y + \bar{z}_\lambda L_z = V_\lambda \qquad (3)$$

Condition (3) states that the luminous efficiency of each part of the spectrum shall be obtained from the tristimulus values of that part by weighting each primary with its own luminous efficiency, L_x, L_y, L_z. This condition is a special case of equation (1) giving the standard definition of light. $\bar{x}_\lambda L_x$ is the amount of light associated with $\bar{x}$-amount of the red primary, and $\bar{y}_\lambda L_y$ and, $\bar{z}_\lambda L_z$, similarly are those associated with the other two primaries. Since, as has already been pointed out, the standard definition of light is strictly additive, the total amount of light associated with unit radiance for each part of the spectrum, specified by $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$, must equal the luminous efficiency, V_λ, of that part.

This special case of the general statement (1) of the additivity of light is known as Abney's law. Abney's law is prevented by the Helmholtz-Kohlrausch effect from being in strict accord with the facts. But in 1931 it was considered more important to make the standard observer accord with the strictly additive definition of light about to be adopted as standard than to try to take account of the Helmholtz-Kohlrausch effect, at that time not thoroughly understood.

Fig. 1 shows the tristimulus values, $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$, of the equal-energy spectrum derived in accord with equations (2) and (3). Note that none of these values is less than zero; this property results from the choice of primary colors. It is also true that the areas beneath the three curves are equal; this property results from the choice of units in terms of which to express the amounts X, Y, Z, of the primaries. Furthermore it is true that the sum of the tristimulus values at each wavelength expressed in luminous terms, is the luminous efficiency at that wavelength, V_λ, in accord with condition (3). Because of a rather surprising property, not yet mentioned, introduced by the choice of primaries, the red and blue primaries (X and Z) are completely unassociated with any luminous value (Judd, 1930, 1933); that is, $L_x = L_z = 0$; therefore all of the luminous value is associated with the amount of the green primary (Y), and the $\bar{y}_\lambda$-curve shown in Fig. 1 is identically the same function of wavelength as the luminous efficiency (V_λ) function.

For the last twenty years measurements of light and color have been made in accord with tristimulus values, X, Y, Z, defined in terms of the tristimulus values of the spectrum, $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$, and the spectral radiance, E_λ of the light to be specified, thus:

$$\begin{aligned} X &= \int E_\lambda \bar{x}_\lambda \, d\lambda \\ Y &= \int E_\lambda \bar{y}_\lambda \, d\lambda = \int E_\lambda V_\lambda \, d\lambda = B/K_m \\ Z &= \int E_\lambda \bar{z}_\lambda \, d\lambda \end{aligned} \qquad (4)$$

The Y-tristimulus value gives the amount of the light (directly in lumens if multiplied by K_m), and all three tristimulus values, X, Y, Z, taken together, specify its color. The system is completely self-consistent, logical, and convenient to use in practice; indeed, it has been found to be of very great practical value. We have next to inquire into how well these definitions of light and color have been found to accord with what actual observers see.

Does the Standard of Light Agree With Actual Observations?

Of course, the Helmholtz-Kohlrausch effect prevents equal amounts of light from always appearing equally bright. What it really tells us is that light is not strictly an additive quantity. But since light has been defined as a strictly additive quantity, rediscoveries of the Helmholtz-Kohlrausch effect have taken the form of finding special cases in which lights of equal luminance fail to appear equally bright. MacAdam (1948), Dresler (1953), and Chapanis and Halsey (1953) have found that, to produce equal brightness, lights of equal luminance should be used only for chromaticities between that of daylight and the yellow part of the spectrum (570 to 580 mμ). As the chromaticity of

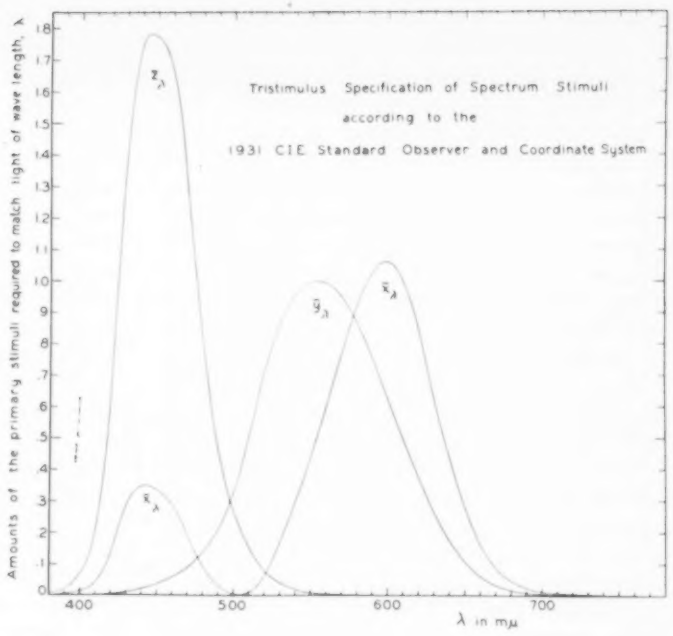

Figure 1. Tristimulus specifications of spectrum stimuli according to the standard observer and coordinate system recommended by the International Commission on Illumination in 1931. These specifications refer to the equal energy spectrum, and the units of the primary stimuli are adjusted so that their combination in equal proportions matches the equal-energy stimulus; that is, the areas of the three curves have been adjusted to equality by choice of units. These three functions define the properties of the 1931 C.I.E. standard observer.

the light departs from this daylight-to-yellow range, less and less luminance is required to produce equal brightness. The answer to the question: Does the standard of light agree with actual observations?, is therefore, *no*. Furthermore, discrepancies of this kind should have been expected from the work of Kohlrausch (1923, 1937) and Dresler (1938). The real meaning of these later studies is that more people are finding out about the Helmholtz-Kohlrausch effect, and, to be sure, are finding that the amount of the effect is large enough to be of some practical importance.

Does the Standard of Color Agree With Actual Observations?

This question may be expressed as follows: If any two colors differing in spectral composition are found by the 1931 CIE standard to have identically the same triad of tristimulus values, X, Y, Z, do these colors look alike when viewed by an observer of normal color vision Almost immediately after the standard definition of color was recommended in 1931, such tests were made and almost invariably the answer was found to be, *no*. In comparing a mixture of spectrum red plus spectrum green to match a spectrum yellow, for example, most observers might say that the standard mixture is too green but others would say it is too red. As long as we can find a good number of observers to cast a minority vote, we say that the standard definition of color has been fairly well supported. Hardly anyone has exactly standard color vision, just as hardly anyone has exactly average height.

Not until 1948 did there appear results of tests in which all actual observers disagreed with the standard in the same sense. Jacobsen (1948) and Judd (1949) found the standard definition of color inapplicable to the colorimetry of rutile and anatase forms of titanium-dioxide pigment. As a result of these and similar checks on near-white surfaces and nearly transparent media (kerosene and other refined petroleum products compared to yellow tinted glasses), some segments of American industry commenced to reduce their spectrophotoemtric data by means of a revised Z-function, higher in the neighborhood of 400 mμ than the standard by about a factor of 5 (CIE, 1951).

Redetermination of the Color-Mixture Functions at the NPL

As a result of an American attempt to have the CIE revise the definition of color by changes in the short-wave end of the spectrum, important for colorimetry, though relatively unimportant for photometry, a redetermination of the color-mixture functions was undertaken by Dr. W. S. Stiles at the National Physical Laboratory in Great Britain. Perhaps, *redetermination* is not quite the correct word. Guild and Stiles have pointed out that the color-mixture functions basic to the standard definition of color have never really been determined directly. As we have seen, they were merely inferred from the chromaticities of the spectrum

colors found by Wright (1928-1929) and Guild (1931) combined with the standard luminous-efficiency function, V_λ, on the assumption that Abney's law is strictly valid. What has been undertaken by Stiles is therefore a careful determination, first in the history of color measurement, of the amount of spectrum red, spectrum green, and spectrum blue radiant flux required by a sufficiently large and representative group of observers (50 or 60) to color match the other parts of the spectrum. Preliminary results for 10 observers for both a 2-degree and a 10-degree field have already been published (Stiles, 1955).

Whether Stiles' final results will be found worthy of adoption as the basis of a new definition of color remains to be seen. This will depend on how successfully the new color-mixture functions predict actual color matches in titanium-pigment colorimetry and in other tests involving light of complicated wavelength composition. Nevertheless, in spite of their preliminary character, when Stiles presented his results at the 1955 Congress of the CIE in Zürich, it was recognized that a new look might have to be taken at our standards for light and color. The need for a change in the basic philosophy of these standards was suggested by Stiles' attempt to derive the standard luminous-efficiency function from his preliminary 2-degree color-mixture functions by means of Abney's law. He found that by weighting these functions by the standard luminous efficiencies of the spectrum primaries used, the sum was far from agreement with the standard luminous-efficiency function, V_λ, in the other parts of the spectrum. He found that by weighting them with the factors derived from photometric settings by the actual observers used, the disagreement was still present. In short, no matter how the color-mixture functions are weighted they will not sum to the standard luminous-efficiency function.

Fig. 2 compares the standard luminous-efficiency function ($V_\lambda = \bar{y}_\lambda$) shown, as a solid line, with the sum of Stiles' preliminary 1955 color-mixture functions, both for the 2-degree and the 10-degree field when these functions are weighted by factors producing nearly the best agreement possible. We need not pay attention to the 10-degree field data (large circles) because they ought not to sum to the standard luminous-efficiency function developed to apply to 2-degree observation. The sum of the 2-degree color-mixture functions, however, is seen to be higher, not only in the short-wave part of the spectrum, but, when reduced as shown to unit maximum, substantially higher in nearly all parts of the spectrum. These results suggest, therefore, not merely a minor revision for the short-wave part of the spectrum, unimportant in photometry, but a major revision throughout the whole spectrum, in the function to be used in the definition of light.

New Look

There are several views that might be taken of the preliminary results from the National Physical Laboratory:

(1) Let us wait until the final results are available before we think what bearing these color-matching data have on the standard of light; maybe these preliminary data are misleading.

(2) Let the standard of color eventually be defined in whatever way it has to be defined, but let the standard definition of light remain the same as it has been for the last 20 years, that is, based on the principle that the standard luminous-efficiency function is the reciprocal of the radiance required

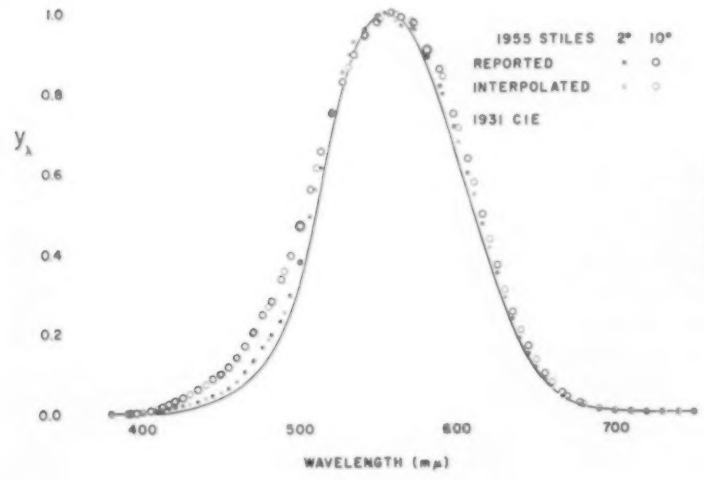

Figure 2. A comparison of the C.I.E. standard luminous-efficiency function (solid line) with the sum of Stiles' color-mixture functions weighted to produce nearly the best agreement possible and then reduced to unit maximum.

at each wavelength to produce fields appearing equally bright for the average, normal eye.

(3) Let the standard of light be revised to accord with a weighted sum of whatever color-mixture functions are finally adopted in a revised definition of color.

Not many of the delegates at the Zürich Congress of the CIE took the view that the preliminary color-mixture functions reported by Stiles are misleading in respect to their bearing on the standard definition of light. It was recognized that most, if not all, of the discrepancy is ascribable to the Helmholtz-Kohlrausch effect. Furthermore, there were also presented at the Zürich Congress of the CIE some confirmatory measurements by Sperling at the U. S. Naval Medical Research Laboratory, New London. Sperling determined directly for the three observers, not only color-mixture functions, but also luminous-efficiency functions by the method of direct visual comparison. Two of the three sets of data showed the color-mixture functions expressed in luminous terms to sum to a wavelength function broader than the luminous-efficiency function for that observer.

The objection to the second view, that independent definitions of light and color eventually be established, is that the contradictory character of the two definitions would be very evident. Thus, generally, any two samples of radiant flux of different spectral compositions found to have exactly the same colors by a definition based upon actual determination of color-mixture functions for the average eye would, on applying the present definition of light, be found to correspond to different amounts of light. By this view, therefore, we would continually be placed in the untenable position of saying that pairs of lights that cannot be distinguished by the average eye, nevertheless, by the average eye have different luminances.

On this account, many of the delegates at the Zürich Congress (for example, Stiles, 1955; Judd, 1955; and MacAdam, 1955) have taken the third view, which looks forward to the eventual establishment of new definitions of light and color, perfectly congruent, just as the present definitions are. The present definitions are congruent because the definition of color has been made to conform to a previously formulated definition of light. The new definitions of light and color would be made congruent by taking for the new definition of light a new luminous-efficiency function computed as some weighted mean of the color-mixture functions to be adopted, the particular weights assigned to be chosen so as best to accord with the needs of practical photometry.

The advantage of this third view is not that it yields congruent definitions of light and color; the present definitions also yield perfect congruence. Nor is it that the third view defines light in such a way that equal amounts of light always appear equally bright to the average observer; as we have seen, no additive definition of light can possibly meet this condition; the Helmholtz-Kohlrausch effect prevents it. No, the advantage of the third view is that it promises to meet the requirement that when lights are found to be equal in color by the new definition, an observer of average, normal color-vision will find them really to be equal, and for this condition of match (under which precision of photometric setting is at a maximum), the standard definition of light will indicate the two lights to be identical in amount.

The disadvantage of the new look is that the required luminous-efficiency function will define as equal amounts of light, such amounts of radiant energy for the various parts of the spectrum as careful photometry by an average, normal observer would show do not appear equally bright. Since it would take a long photometric study to show this discrepancy, it would seem that this disadvantage might be tolerable.

Time alone will tell whether or not this new point of view will lead to new and more satisfactory definitions of light and color.

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DISCUSSION

CHARLES W. JEROME:* In the present paper, Dr. Judd in the manner which we have grown to expect of his publications, gives us an insight into the development of color specification, the problems which beset it, the compromises which had to be made, and in general, the "why" of the present system of specification which so many of us use without a clear understanding of its advantages and limitations.

Then, by reviewing the changes which are being contemplated in this system he has given us forewarning of what to be on the lookout for in this direction and some of the possible consequences which may come from them.

I strongly feel that this paper should be required reading by everyone in the field of color measurement and specification.

I have one question to ask Dr. Judd. On the subject of heterochromatic photometry, he implies that the direct visual comparison leads to results which are more uncertain than the cascade method. My thought is that in the latter method, although the uncertainty of the individual steps may be less than in the direct comparison, these uncertainties may be cumulative with the end result that the overall uncertainty may be as bad in one as in the other. I would be interested in knowing Dr. Judd's comments on this.

D. L. MACADAM:** Dr. Judd's presentation of the new look at the measurement of light and color is sound, and lucid, and fair to all points of view. I am in agreement with his dismissal of flicker photometry as a basis of a satisfactory definition of light. I admire his explanation of why no set of three primaries can be found whose combination in positive amounts produces all colors. The statement that Stiles is the first to determine actual color mixture data should help to clear away misconceptions. In comparison with

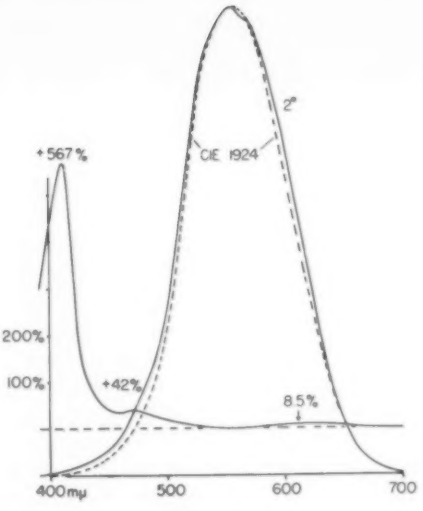

Figure A.

Judd's accomplishments in this paper, the following comments are of minor importance.

In the second paragraph and in the discussion of the Helmholtz-Kohlrausch effect, it is stated that equality of brightness settings are uncertain by a factor of two or more. In his paper, Kohlrausch indicated mean errors of setting ranging from less than 1 per cent to not more than 5.7 per cent. Brenneman, who presented a large body of such data throughout the chromaticity diagram at the spring 1957 meeting of the Optical Society, found and will shortly publish standard deviations of matching of the same order of magnitude as reported by Kohlrausch. Brenneman also found that a single observer can repeat his average settings, at intervals of many weeks, with uncertainties of not more than about 10 per cent. Various observers, however, do disagree by factors as great as 2. This, however, is characteristic of practically all psychophysical data, including conventional luminosity values.

At its 1939 Plenary Session the CIE adopted the term "luminosity" for V_λ. I can find no record of that action being rescinded. Various writers and even some committees of the CIE have more recently used other terms, such as "relative luminous efficiency" for this quantity. But failure, even by CIE committees, to follow a formal recommendation does not constitute withdrawal of that recommendation.

It may be of interest to note that the delegates from the USSR at Zurich in 1955 originated the proposal to drop from the definition of luminance flux the phrase "in accord with its ability to produce luminous sensations." Several Russian papers at the NPL Symposium on Visual Problems of Color, September 23-25, indicate further study and contributions to this subject.

Although the curves in Fig. 2 are distinctly different, they suppress some really startling differences between Stiles' results and the standard CIE data. The curve for the ratio of these two sets of data (2° field), shown in Fig. A, indicates an excess of 575 per cent at 410 mμ. Stiles' 10° result for 410 mμ is 975 per cent greater than the CIE value. The curve in Fig. A indicates the order of magnitude of revisions of luminosities of highly chromatic lights if they are computed by use of Stiles' data rather than the CIE data.

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L. E. BARBROW:* I recommend heartily to those illuminating engineers concerned with photometry who may read this discussion but who have not read Judd's paper critically, that they will be well rewarded if they do so. This paper explains the close ties that exist between photometry and colorimetry as well as the challenge that a contemplated revision of the Standard Observer for Colorimetry poses for photometry.

Of the three views into the future discussed by Judd on pages 68 and 69, view 2 would be the most comfortable for photometrists since it implies no changes of importance now or in the future of the standard luminous efficiency function but, as Judd explains, this would be untenable if the definition of color is changed. He makes a good case for view 3 which would require a revised standard luminous efficiency curve computed as some weighted mean of the color-mixture functions. However, in view of the severe hardship that such a revision would place upon photometry, which is now practically entirely objective, with multitudes of receivers corrected to the standard luminous-efficiency function, it would appear that view 1 might deserve greater attention.

The Standard Observer for Photometry and Colorimetry should, of course, be fairly representative of human eyes the world over. The revisions now contemplated are based on color-mixture data of 50 or 60 observers. Two questions arise. (1) Are these observers really representative of observers on a world-wide basis, and (2) would, perchance, the luminous-efficiency functions of Stiles' individual observers or more representative observers computed from their individual color-mixture functions overlap the current standard luminous-efficiency function? If my question (2) gets an affirmative answer, the revision of the Standard Observer for Colorimetry need not be so painful to the photometrist since one of the color-mixture functions in the new system might well be left identical to, or at least nearly like, the current luminous-efficiency function.

D. B. JUDD:** In reply to Mr. Barr's oral question regarding how much change in lumen values of sources of high color temperature (such as a daylight fluorescent lamp) is to be anticipated should the luminous-efficiency function be changed from the 1931 CIE standard to that based upon the Stiles 2-degree pilot data, I can cite a computation that I have made for the step-up from the primary standard (2042K) to CIE source C. This computation showed that source C (representative of average daylight) would be rated higher in lumen value by 1.4 per cent by the Stiles 2-degree pilot data than by the present standard data (CIE 1931). Because of the Helmholtz-Kohlrausch effect, luminous-efficiency functions derived from color-mixture functions are broader than those derived by the equality-of-brightness and cascade methods, and the fact that most of this broadening must be toward the shortwave side in order to yield the same step-up from 2042K to 2788K is what would cause higher lumen values to be assigned to high color-temperature sources. Should the time ever come to consider seriously the very inconvenient proposal of revising the standard luminous-efficiency function, the fact that such a proposal implies slightly higher lumen values for the commercially important sources of high color temperature would undoubtedly be put forward as a point in favor of the revision.

Mr. Jerome has raised the question whether the cascade method of heterochromatic photometry because of cumulative error may not really be less certain than the method of direct visual comparison. I do not know the answer to this question, but I think I know why the cascade method is preferred. If each photometric comparison involves only a small chromaticity difference, the observer adjusts the luminances until the dividing line most nearly disappears and proceeds confidently because he can reproduce his settings from one session to another and all sessions show high precision; he thus has at least the illusion of having achieved a final result of high certainty. On the other hand, to ask an observer to make a setting of brightness match by direct visual comparison of two lights chromatically very different (like red and blue) often seems to the observer like asking him to do the impossible. Various criteria for the setting may be used. In my own attempts at such settings, I have noted that the field much brighter than the other appears more solid and closer; so I have sometimes used the criterion of adjusting the two luminances until the fields appear equally solid. At other times, I have adjusted the luminances until the fields appear equally far away, but often I do not know exactly by what criterion I have made the setting. Judging by their remarks, other observers have similar doubts about the reliability of their settings; and I suggest that the method of direct equality-of-brightness settings takes second place relative to the cascade method because the observer is continuously reminded of the uncertainty of his final result.

Dr. MacAdam is correct in his statement that the CIE has never formally withdrawn its recommendation of the term "luminosity" for V_λ. At the 1951 Stockholm meeting of the CIE, however, the following revised definition was adopted (Vol. III, Proc. page 59):

"Relative luminous efficiency (of a monochromatic radiation). Ratio of the luminous efficiency K_λ of that radiation to the maximum luminous efficiency K_m. Symbol: V_λ."

I take this action as support for my use of the term "relative luminous efficiency" instead of "luminosity"; but it should be pointed out that in several places in my paper I have written simply "luminous efficiency" when I should have written "relative luminous efficiency."

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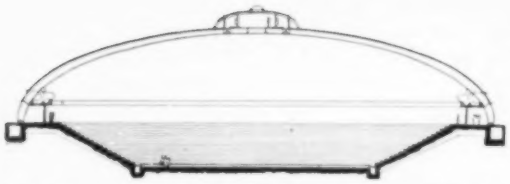
**Author.

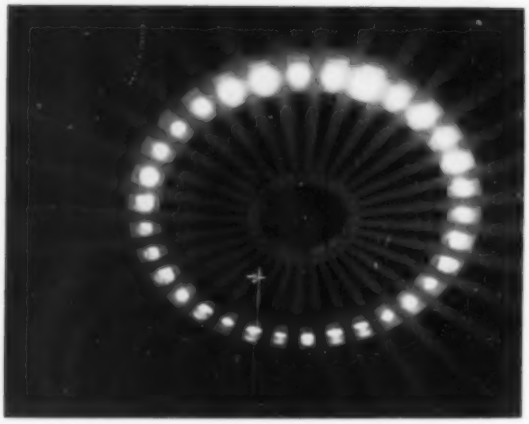
Index to 1957—

Officer-Committeeman Directory

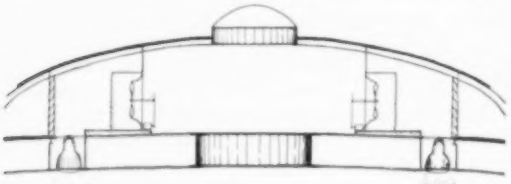
The annual Index to 1957, published as Part II of this issue, this year gives the business addresses of I.E.S. officers and committee personnel for 1956-1957 and 1957-1958, and so can be used as a Directory of these active I.E.S. members.



W. A. Alexander Memorial Coliseum, seating 7500, has playing floor 25 feet below ground level. Clear span distance from foot-of-base to foot-of-base is 270 feet.

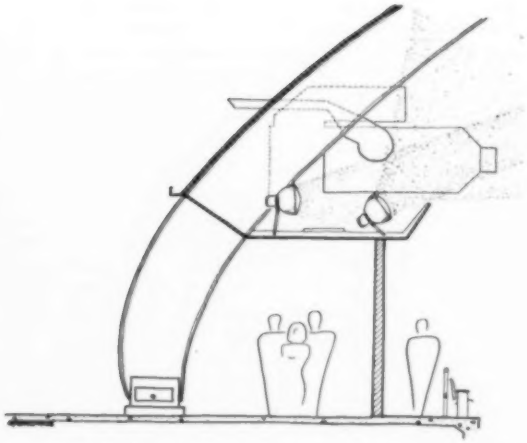


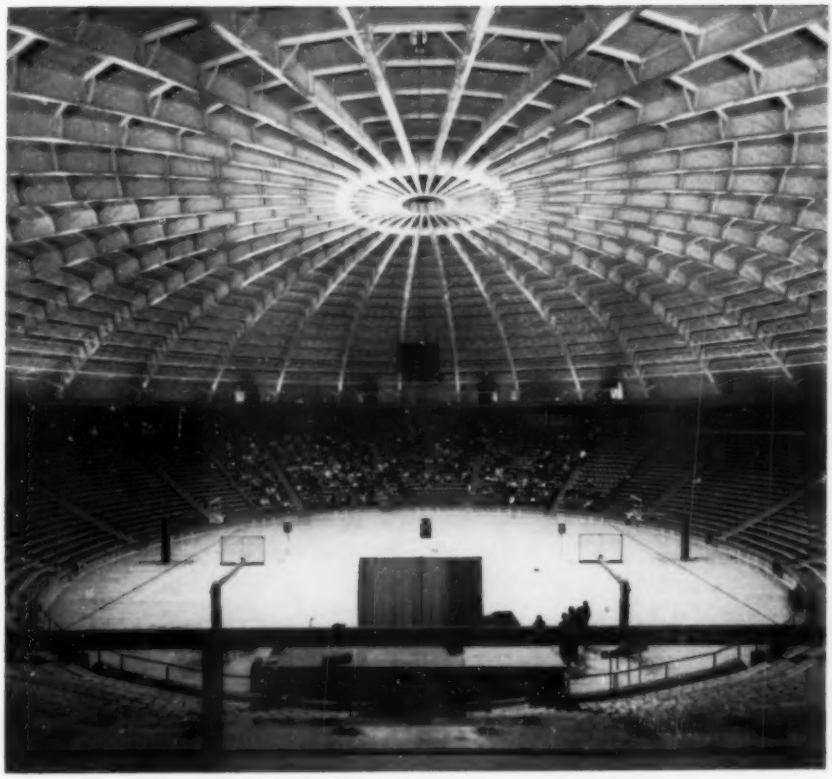
Downlighting from cupola provides 55 to 60 footcandles on the playing courts. Cross-section drawing, below, shows units mounted in annular light trough just below the cupola floor. Access is from the roof of the arena.



Architectural Design

General illumination for spectator area is from the cove. Indirect lighting on the ceiling also provides an artificial "sky," simulating outdoor conditions on an overcast day. Cove lighting provides 7 to 8 footcandles.





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Answers Lighting Questions

By CHARLES F. HOWE

ARCHITECTURALLY pleasing and desirable features in a building design sometimes create problems in lighting. In the case of the W. A. Alexander Memorial Coliseum, however, the architectural design, itself supplied the answers to the lighting requirements.

Located on the campus of Georgia Tech in Atlanta, the arena seats 7500 spectators, primarily for basketball. The circular playing floor, which has a diameter of 130 feet, has a regulation tournament court and two practice courts at right angles to the main court. The spectator seating is stepped in concentric circles around the playing floor. Since the backboards are of clear Plexiglas, there is not a poor seat in the arena.

AUTHOR: Consulting Engineer, Atlanta, Ga. Architect for the installation was Aeck Associates, Electrical Contractor was Brooks-Allison Co., both also of Atlanta. Installation won first prize in the Georgia Section's contest for My Most Interesting Lighting Job.

The building is framed from 32 rigid free-standing steel arches which ride on pin joints at the base, and frame into a 12-foot diameter steel ring at the top. The clear span distance across from foot-of-base to foot-of-base is 270 feet.

The cross-section drawing shows the construction of the building, with the entrance at ground level and seating stepping down to the playing floor, which is 25 feet below the ground level, or a total of 70 feet from top to floor.

These were the lighting requirements:

(1) To light the arena in a manner that would not detract from the beauty of the steel structure.

(2) To provide a level of from five to ten footcandles over the spectator area.

(3) To provide a level over the playing court of from 50 to 60 footcandles.

(4) To accomplish this without creating a difficult maintenance problem.

Maintenance considerations were, in fact, of prime importance. The 70-foot height of the arch above the playing floor — about the height of a 5-story building — would make relamping of pendent fixtures a difficult chore. It was also felt that pendent fixtures would detract from the geometrical pattern of the steel arches.

Downlighting

An architectural feature of the building design proved the solution to this problem. A cupola was planned for the top of the arena, to house the fans required to exhaust air and smoke. The roof of the arena serves as the floor of the cupola, access to which is from the roof. A ladder placed over the curved section of the roof enables a man to reach the flat portion, from where he can walk to the cupola. Downlights mounted in or below the floor of the cupola would be easily maintained by access from the top. This arrangement is, furthermore, attractive and in keeping with the building design.

An annular opening was left in the floor of the cupola, 33 feet in diameter and 36 inches wide. Below this opening a circular metal trough was installed, the bottom of the trough being flush with the bottom of the arches. Holes were cut in the bottom of this trough in which high-bay industrial concentrating type reflectors in adjustable gimbal rings were mounted. There are 32 of these fixtures, one between each two adjacent arches; 18 use 1500-watt incandescent lamps and 14 use 1000-watt color corrected mercury. The gimbal rings were for adjustment in aiming the lights on the playing floor, and once adjusted the rings were locked in place. Thus, for servicing and re-lamping, the reflector is removed from the gimbal ring, serviced and returned to the original aiming position.

Maintained level of illumination on the court from the downlights is from 55 to 60 footcandles.

Cove Lighting

Efficiency and effectiveness in basketball, as in many other sports, depend a great deal upon the speed with which the players can determine the location, direction and velocity of the ball. This visual acuity is generally highest when playing outdoors under a dull or overcast sky. Since the ceiling of the arena is parabolid in shape, similar to the sky as it appears to us, indirect lighting reflected from the ceiling would produce a small "sky" within the building.

Again, a detail of building construction was used to advantage for the lighting. The architect wanted a covered walk completely surrounding the outside of the arena. To accomplish this, he stopped the roof at a point about 10 feet from the ground. With the wall moved in, again about 10 feet, and a ceiling provided, a covered walkway was obtained, completely surrounding the exterior of the arena. This walkway forms a ledge completely surrounding the interior of the arena. With a minimum amount of baffling, to keep the lights below the sight line, a large cove is formed.

Computations for the cove lighting were relatively simple. The arches at their base were spaced 26 feet on centers, and up at the top at the framing ring, they are 1½ feet apart. Thus a pair of arches forms a pie-shaped segment of ceiling. For a level of from five to ten footcandles, given the reflectance of the ceiling, the efficiency of the cove and the efficiency of the ceiling as a projector, calculations arrived at the specification of four floodlights per bay — two 1000-watt incandescent and two 400-watt color corrected mercury. To wash out sharp shadows on the ceiling, caused by the purlins and steel bracing in the corresponding bay directly opposite, one additional 1000-watt incandescent narrow beam floodlight was added per bay, making a total of five lamps per bay. In bays where unit heaters are located, two 500-watt lamps were substituted for one 1000-watt.

Doors from the covered walk provide access to the catwalk in the cove above. A man can walk completely around the arena on this catwalk, servicing and re-lamping as he goes.

The indirect lighting from the cove provides a general illumination of 7 to 8 footcandles maintained, for the spectator area as well as the diffused "sky" lighting for the court.

The obvious compatibility of architectural and lighting plans has, in this case, worked out to the advantage of each, with the player and spectator the final beneficiaries.

INSTALLATION AT THE BUFFALO SAVINGS BANK, MAIN AND GENESEE STS., BUFFALO, N. Y.

Floodlighting a Building and Sidewalk

LIGHTING OBJECTIVE: To floodlight a building facade and the sidewalk in front of it, from equipment locations restricted to the building, and without altering the architectural lines of the building.

GENERAL INFORMATION: This bank is in the center of the downtown business district. It is located on a corner with frontage on three streets totaling 440 feet. The height to the cornice is 50 feet. The sidewalk is 22 feet wide. The facade is smooth gray stone of 45 per cent reflectance. The sidewalk reflectance is 35 per cent.

INSTALLATION: The facade and sidewalk are illuminated by eight hundred twenty-eight 150-watt, PAR-38 projector lamps, spaced approximately 6 inches on centers, alternate spot and flood distribution. The lamps are enclosed in a continuous false cornice (see Fig. 2) of stainless steel extending from the stone cornice of the building. Lamp shielding is 38 degrees crosswise by 24 degrees lengthwise. The false cornice is mounted in 105 sections, each slightly more than 4 feet long. Access to lamps and wiring is through hand-holes with weatherproof covers extending nearly the full length of each section. The lamps are approximately 2 feet out from the building and are mounted on channels with the lamp axis vertical. The total load is 124 KW.

(over)

A.I.A. File No. 31

Floodlighting a Building and Sidewalk (Continued)

Illumination on the sidewalk approximately 18 months after installation was:

feet out from building facade	
1	42 fc
2	50 fc
5	46 fc
10	40 fc
15	30 fc
20	20 fc

Brightness of the facade was:

feet above ground (approx.)	
1	1 fL
5	1 fL
20	2 fL
30	3 fL
40	5 fL
45	12 fL

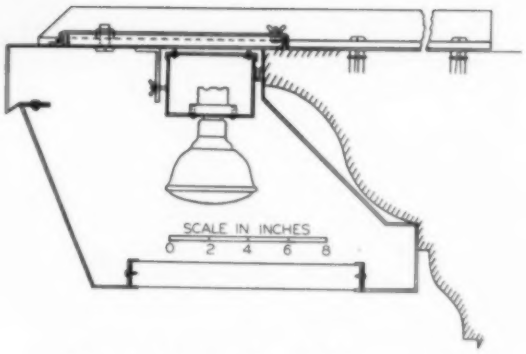

Figure 2. Section through false cornice.

Lighting designed, fabricated and installed by Machwirth Bros., sheet metal fabricators and the Robertson Electric Co., Inc., electrical contractors, both Buffalo, N. Y.

Lighting data submitted by Niagara Mohawk Power Corp., Buffalo, N. Y., as an illustration of good lighting practice and to aid in the design of similar installations.

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Measurement and Specification of Color Rendition Properties of Light Sources

By DOROTHY NICKERSON

BEFORE OUR knowledge of the effects of artificial light is satisfactory we must solve the problem of the part played by color." This statement is as true today as it was in 1910, almost fifty years ago, when Herbert E. Ives[1] first discussed color measurements of illuminants before this Society.

The two methods used in his day to measure color of light sources are essentially the same today, although both are now highly standardized: spectroradiometric, in which the relative intensities of the spectra of various light sources are measured wavelength by wavelength, and colorimetric, in which the color of each source is matched by methods of color mixture. The validity of the color matching method is stated in Grassman's law[2] which says that lights of the same color produce identical effects in mixtures, regardless of their spectral composition. Unfortunately for the illuminating engineer, it does not follow that objects seen under light sources of the same color will appear alike in color. The color distortion due to spectral differences in light sources of the same color is one of the problems of color rendition. This problem is fairly simple compared to that which involves also a shift in the color of the light source, for the eye adapts[3] itself to such shifts. Formulas for computed data must take into account the state of an observer's adaptation if they are to predict correctly the color an observer will perceive. In addition to adaptation to the color of the light source, there is adaptation to the background and surrounding conditions under which the observations are made. This all results in a net shift, and it is this net shift we must hope to predict if the illuminating engineer is to have a color rendition rating (whether one — or multi-numbered) that he can use with confidence in a practical situation.

Colorimetry today is a science on so firm a basis that it is doubtful whether many persons realize how much additional information is needed before color rendition of a light source can be predicted accurately. The purpose of this report is to review some of the basic procedures and information that are available and necessary for this work, and to point out what still is lacking, or available in only a very limited way, and what remains to be done.

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 9-13, 1957, Atlanta, Ga. AUTHOR: Color Technologist, U. S. Department of Agriculture, Washington, D. C., and Chairman, Subcommittee on Color Rendition, I.E.S. Light Sources Committee. A Transaction of the I.E.S.

What To Use As a Standard

In much color work the first problem is what to use as a standard light source. Back in 1910 Dr. Ives suggested "average daylight," to lie between the extremes of "blue light from the sky" and "the color of low sun," a color that he thought agreed closely with the visible radiation of a black body at 5000K. But even if 5000K were the best choice, obviously one color is not enough, and in 1931 the International Commission on Illumination (CIE) adopted three standard sources, identified as *A*, *B*, and *C*. *A* is intended to be typical of light from a gas-filled incandescent lamp (2854K; *B* is an approximate representation of noon sunlight (4800K); *C* is an approximate representation of average daylight (6740K). For colorimetry of object colors such sources have served an important purpose. But when one wishes to select or compare light sources, even three is not enough. For work involving color grading and color matching the color of CIE Source *C* has been found to be yellower than the color of the daylight used and preferred for this purpose (7400K - 7500K).[4,5]

What is needed is a one-dimensional series with continuous, reasonably smooth spectroradiometric curves that will cover the range from yellowish to bluish whites. For this purpose the one-dimensional series of sources defined by the Planck radiation law has the advantage of having continuous and maximally smooth curves and a convenient and precise definition. But the curves bear little resemblance to those of actual light sources except in the low color temperature range of the incandescent tungsten lamps. Fig 1. In the range of daylight colors use can be made of the one-dimensional series described by Gibson in 1940,[6] known since then as the Abbot-Gibson series. Fig. 2. In this

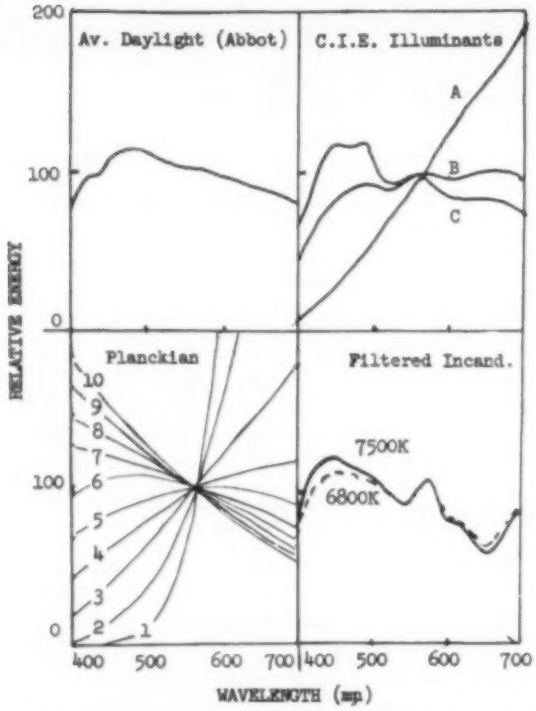

Figure 1. Relative spectral energy distributions for Average Daylight (Abbot); CIE standard Sources *A*, *B*, and *C*; Planckian black-body radiators, 1 to 10 thousand K, and filtered-incandescent (Corning No. 5900 glass) at 6800K and 7500K.

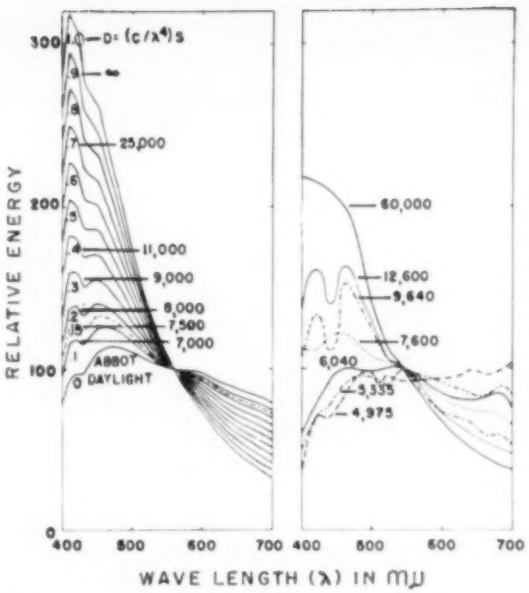

Figure 2. Theoretical daylight curves derived by Gibson from different proportions of Abbot sun-outside-atmosphere and skylight calculated by use of inverse λ^4 scattering relation; and for comparison, curves of daylight measured in 1939 by Taylor and Kerr.

series curves representing sources of desired daylight color may be derived by combining different proportions of Abbot's 1923 measurements of sun-outside-the-atmosphere with the bluest possible skylight, calculated from his data by use of the Rayleigh scattering equation ($1/\lambda^4$). Values of the chromaticity coordinates computed for this series lie on a straight line very close to the Planckian locus. In work involving color rendition of light sources intended to approximate daylight in the 7400K - 7500K color temperature range, the Abbot-Gibson curve consisting of 85 per cent Abbot daylight and 15 per cent blue sky has been particularly useful. The curve for Abbot daylight alone computes to a color that plots on the Planckian locus just above 6000K, with 10 per cent blue sky it is about 7000K, with 20 per cent about 8000K, and with 30 per cent about 9000K. Because these data are of considerable current use (and are not available in detail except in a 1940 mimeographed report[7] now out of print) they are given in Table I. By interpolation the approximate spectral energy distribution for any measured color temperature of the sky may be derived

In writing specifications or in performing instrumental colorimetry, the standards discussed are very useful. But when it is necessary to make observations it becomes dishearteningly clear that most of these light sources are either completely theoretical, or quite impractical to use for illuminating objects that are to be observed. Daylight is used most often in making observations of the color of objects, and the "daylight color" certainly is the one most often wanted. But while approximations can be made, no real colorimetric precision is possible for experiments made under a light source that cannot be specified accurately for the duration of the experiment. As we continue to compile colorimetric information it becomes increasingly evident that to solve some of our color rendition problems we need observations made under very precisely measured conditions of illumination.

The three CIE standards include a gas-filled lamp operating at a color temperature of 2845K (1948), and this lamp used with double liquid filters. Use of these liquid filters is possible in instrumentation, but it is not very convenient. For work involving filters, the liquid filters often are supplanted by Corning's glass filter No. 5900, which is designed to convert the color of incandescent lamps to that of daylight with as close a match to

TABLE I — Abbot-Gibson Data for Spectral Energy Distributions of Skylight.

Wavelength mμ	Daylight[1] S_e	Blue Sky[2] S_b	Blue Sky + Average Daylight in Varying Proportions										
			.05+.95[3]	.1+.9	.15+.85	.2+.8	.3+.7	.4+.6	.5+.5	.6+.4	.7+.3	.8+.2	.9+.1
380	62.0	292.4	73.5	85.0	96.6	108.1	131.1	154.2	177.2	200.2	223.3	246.3	269.4
90	63.9	271.6	74.3	84.7	95.1	105.4	126.2	147.0	167.7	188.5	209.3	230.1	250.9
400	73.4	282.0	83.8	94.3	104.7	115.1	136.0	156.8	177.7	198.5	219.4	240.3	261.1
10	91.5	318.4	102.8	114.2	125.5	136.9	159.6	182.3	205.0	227.7	250.4	273.1	295.8
20	97.0	306.6	107.5	118.0	128.4	138.9	159.9	180.8	201.8	222.7	243.7	264.7	285.6
30	96.9	278.7	105.8	115.1	124.2	133.3	151.4	169.6	187.8	206.0	224.2	242.4	260.6
40	102.9	270.0	111.3	119.6	128.0	136.3	153.0	169.7	186.4	203.2	219.9	236.6	253.3
450	109.6	262.8	117.4	124.9	132.6	140.2	155.6	170.9	186.2	201.6	216.9	232.2	248.0
60	112.0	246.0	118.5	125.4	132.1	138.8	152.2	165.6	179.0	192.4	205.8	219.2	232.6
70	113.5	228.8	119.2	125.0	130.8	136.6	148.1	159.6	171.1	182.6	194.2	205.7	217.2
80	113.6	210.5	118.5	123.3	128.1	133.0	142.7	152.3	162.0	171.7	181.4	191.1	200.8
90	112.1	191.2	116.0	120.0	124.0	127.9	135.8	143.8	151.7	159.6	167.5	175.4	183.3
500	110.7	174.2	114.0	117.0	120.2	123.4	129.8	136.1	142.4	148.8	155.1	161.5	167.8
10	108.5	157.7	110.9	113.4	115.9	118.4	123.3	128.2	133.1	138.0	143.0	147.9	152.8
20	105.9	142.4	107.7	109.6	111.4	113.2	116.9	120.5	124.2	127.8	131.5	135.1	138.8
30	103.4	128.9	104.7	106.0	107.2	108.5	111.0	113.6	116.1	118.7	121.2	123.8	126.3
40	101.7	117.6	102.6	103.3	104.1	104.9	106.5	108.1	109.7	111.3	112.8	114.4	116.0
550	100.9	108.4	101.1	101.6	102.0	102.4	103.2	103.9	104.7	105.4	106.2	106.9	107.7
60	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
70	99.1	92.3	98.9	98.4	98.1	97.8	97.1	96.4	95.7	95.0	94.4	93.7	93.0
80	98.6	85.7	98.1	97.3	96.7	96.0	94.7	93.4	92.1	90.8	89.6	88.3	87.0
90	98.3	79.8	97.4	96.4	95.5	94.6	92.7	90.9	89.0	87.2	85.3	83.5	81.6
600	97.4	73.9	96.2	95.0	93.9	92.7	90.4	88.0	85.7	83.3	81.0	78.6	76.3
10	95.2	67.6	93.8	92.4	91.1	89.7	86.9	84.2	81.4	78.6	75.9	73.1	70.4
20	93.1	62.0	91.7	90.0	88.4	86.9	83.8	80.6	77.5	74.4	71.3	68.2	65.1
30	91.0	56.8	89.2	87.6	85.9	84.2	80.7	77.3	73.9	70.5	67.1	63.6	60.2
40	89.3	52.4	87.4	85.6	83.8	81.9	78.2	74.5	70.8	67.1	63.4	59.7	56.0
650	87.5	48.2	85.7	83.6	81.6	79.6	75.7	71.8	67.8	63.9	60.0	56.1	52.1
60	86.0	44.6	84.0	81.9	79.8	77.7	73.6	69.4	65.3	61.1	57.0	52.9	48.7
70	84.6	41.3	82.5	80.3	78.1	75.9	71.6	67.3	62.9	58.6	54.3	49.9	45.6
80	83.3	38.3	80.9	78.8	76.6	74.3	69.8	65.3	60.8	56.3	51.8	47.3	42.8
90	81.4	35.3	79.2	76.8	74.5	72.2	67.6	63.0	58.4	53.8	49.1	44.5	39.9
700	79.1	32.4	76.8	74.4	72.1	69.8	65.1	60.4	55.8	51.1	46.4	41.7	37.1
10	76.8	29.7	74.4	72.1	69.7	67.4	62.7	58.0	53.3	48.6	43.8	39.1	34.4
20	74.4	27.2	72.0	69.7	67.3	65.0	60.2	55.5	50.8	46.1	41.4	36.7	32.0
30	72.2	25.0	69.8	67.5	65.1	62.8	58.0	53.3	48.6	43.9	39.2	34.4	29.7
40	70.2	23.0	67.8	65.5	63.1	60.8	56.1	51.3	46.6	41.9	37.2	32.5	27.8
750	68.2	21.2	65.9	63.5	61.2	58.8	54.1	49.4	44.7	40.0	35.3	30.6	25.9
60	66.1	19.5	63.8	61.4	59.1	56.8	52.1	47.5	42.8	38.1	33.5	28.8	24.2
70	63.9	17.9	61.6	59.3	57.0	54.7	50.1	45.5	41.9	36.3	31.7	27.1	22.5
380 }	x .3204	.2319	.3139	.3076	.3016	.2959	.2854	.2757	.2669	.2588	.2513	.2444	.2379
770 }	y .3301	.2318	.3228	.3158	.3092	.3029	.2912	.2804	.2706	.2616	.2533	.2456	.2384
400 }	x .3204	.2320	.3138	.3075	.3016	.2959	.2854						
700 }	y .3304	.2322	.3231	.3161	.3095	.3032	.2915						
c.C.T.	6100K	α	6500K	7000K	7400K	8000K	9300K	11,000K	14,000K	18,000K	25,000K	47,000K	60,000K

[1] S_e, Daylight-Outside-Atmosphere (Abbot, 1923).
[2] S_b, $(C/\lambda^4)\ S_e$.
[3] Data are from 1939 K. S. Gibson tables to D. N.

the spectral energy of daylight as can be obtained by use of a glass filter. In this country this filter is used in many instruments, and when the source-filter color temperature matches that of C, often it is identified as if it were equivalent to C. Used in varying thicknesses this glass can provide a series of colors that vary all the way from the color of the unfiltered light source to that of light of limit-blue-sky. In large size, this same filter is used in lamps to provide a standard source for making color observations.

One of the first questions before your subcommittee* on Color Rendition* was what source should be used as a standard against which to check the color rendition of the test source. Three one-dimensional series of sources were considered:

A. The sources defined by the Planck radiation law,

B Series A to 3000K, and for higher correlated color temperatures an incandescent lamp at 3000K with filters of Corning Daylite glass,

C. Series A to 6000K, and the Abbot-Gibson series from 6000K to limit-blue-sky.

Only one of these was possible for use in practical tests, therefore it was decided that series B would be used in validation, and series C for a formal standard. The very necessity for this division into

*Subcommittee on Color Rendition, IES Light Sources Committee. Members, past and present: A. C. Barr, E. W. Beggs, C. N. Clark, C. W. Jerome, D. B. Judd, Norman Macbeth, Dorothy Nickerson, Ch., C. R. Stilwell, C. E. Swanson, Luke Thorington, A. W. Weeks; Advisors: R. M. Evans, Günter Wyszecki. The scope is to establish a method of measuring and specifying the color rendition properties of light sources, with priority given to fluorescent lamps.

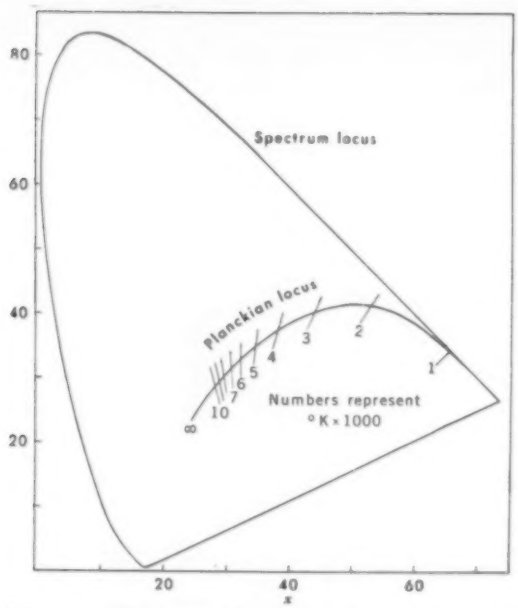

Figure 3. CIE chromaticity diagram in its most widely used (x, y)-form.

a practical and a formal standard indicates how very real the problem of a standard is. But it is the best we can do for the moment.

How Shall Colorimetric Results Be Expressed?

In colorimetry three things are necessary to specify the color of an object: a light source, an object to reflect or transmit the light from that source, and an observer to see it. Since 1931 a considerable amount of careful colorimetric data, much of it based on spectrophotometric measurements, has been compiled in terms that are similar all over the world, wherever modern colorimetry is practiced. This is possible because of the adoption by the CIE of specifications for a standard observer for colorimetry as well as for standard light sources. So often are these two of the necessary three variables kept constant in practice that it has been possible to assemble sufficient data to make great progress not only in specifying color but in correlating the differences in specifications with the size of the color difference they represent.

Tables of data defining the CIE Standard Observer and CIE Standard Light Sources *A*, *B*, and *C* will be found in the *IES Lighting Handbook* together with an example that illustrates the mechanics of computing the color of a particular sample. For more details see chapters on Psychophysics of Color and Quantitative Data and Methods for Colorimetry in reference 3. Refer also to a paper on this program by Judd.[9]

A CIE color specification consists of three numbers, either the tristimulus values X, Y, and Z that are required to establish a match with the sample color; or the tristimulus value, Y, which is a measuse of luminance, and x, y, two of the three chromaticity coordinates (ratios of the X, Y, Z numbers to their total) that by custom are used as coordinates for the form of the CIE chromaticity diagram illustrated in Fig. 3, the form with which we are most familiar. One very useful fact about this diagram is that additive mixtures of any two colors lie along the straight line connecting the two end colors.

The spectrum locus, the Planckian locus, in fact the locus of any light source is fixed on this diagram. Kelly[10] has worked out a color-name designation for lights in which the name limits are expresed by lines drawn on such a diagram. These instances show a unique use for this diagram. It may be noted that they require only two variables, a light source and an observer. The question, "What is white?" becomes important, and for an anchor point, the color representing an equal energy spectrum is used. It plots at the center of the diagram, $x = 0.3333$, $y = 0.3333$, about 5500K.

The minute that an object enters the picture, a choice of a single light source must be made in order for the color of that object to be specified and plotted on the diagram. In this country it is usual for the CIE specification of object colors to refer to colors perceived by the "standard observer" in "average daylight."

Thus the point representing CIE Source *C* becomes the color center of the diagram, the center to which the colors of all objects seen under that light source are related. A great deal of work has been done for the diagram in which *C* is the center that is not available for diagrams in which other sources are the focal point. There is a psychological concept of equally perceptible differences of object colors in which color differences may equal each other regardless of source. This makes it possible to develop scales of hue, lightness, and saturation such as has been done in developing the concept of the Munsell scales of hue, value, and chroma. A distinction should be made between the concept and its representation, for when the concept is illustrated by samples, the samples must be made for a single set of conditions. When Munsell papers were made to represent these scales, the work was done in daylight.

One of the aims of the extensive studies on the spacing of the Munsell system[11] by a subcommittee of the Optical Society of America was to express in terms of the CIE notation for Source *C* enough

surface colors corresponding to their recommendations to define the system adequately. This means that the observations were made in daylight, or under a light source intended to be an equivalent to daylight, and that the results were specified in relation to Source *C*. The loci for constant Munsell hue and chroma for Source *C* are illustrated in Fig. 4 on a CIE chromaticity diagram. Hue and chroma loci for other values show a regular displacement, value by value, for hue and chroma. Thus two important facts become clear: even for daylight conditions and equal luminance, equal distances on the *(x, y)*-diagram do not correspond to colors perceived as equally different, and, for colors that vary in lightness, the same point on the diagram can represent colors that may differ considerably from each other both in hue and in saturation.

The first fact, while it is not always kept in mind, is widely known. For years there has been a search by various workers to find some sort of diagram that would represent more uniform spacing. In a 1947 paper[12] the writer assembled 15 different diagrams in this field, from Judd's first UCS diagram (1935), and covering work by MacAdam, Breckenridge and Schaub, Farnsworth, Scofield-Judd-Hunter, Adams, Moon and Spencer, Saunderson and Milner. There have been others since.[13]

The second fact has not had the attention it deserves, although as a practical matter it is just as important. The most important work that has taken into consideration this change in chromaticness (hue and chroma) for a constant point on the chromaticity diagram (constant dominant wavelength and purity) with change in lightness (or *Y* value), is that of Hunter in his *(a, b)*-diagram and that of Adams in his Chromatic-Value Diagram. The diagram that comes closest to converting CIE data regardless of the value of *Y*, to constant chromaticness is one reported by Nickerson, Judd, and Wyszecki[14] in 1955. This diagram indicates that it is possible to make a close approximation to conversion of CIE data to constant chromaticness as well as to constant chromaticity, but the method is not yet simple enough for practical use, nor is the hue spacing as good as we would like.

While all of this work goes on to find a uniform color space, the *(x, y)*-diagram is still most used. Used with a series of diagrams similar to the one in Fig. 4, but for a range of value levels from dark to light, or used with data based on the MacAdam ellipses of constant size of color difference, it is possible to develop a great deal of information regarding the size of color differences. For daylight conditions we do not yet have all the answers (even now a committee of the Optical Society of America is working on a long-term project regarding uniform color spacing), but we do have enough to make work in colorimetry practical and useful. Munsell notations, directly obtained or converted from CIE specifications, provide a simple and practical method of working with uniform color scales.

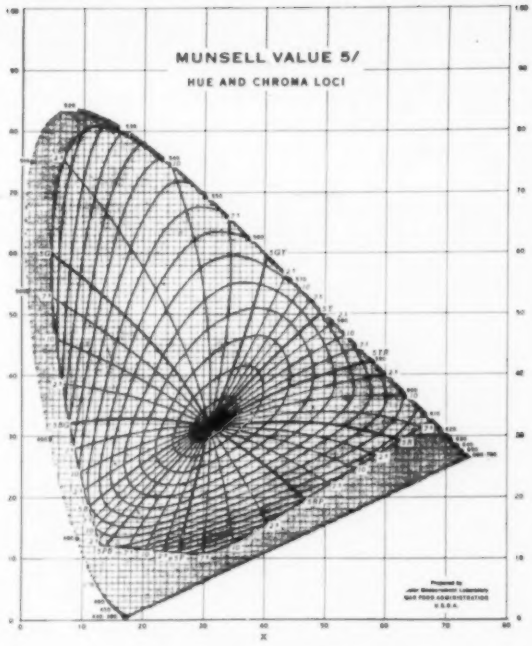

Figure 4. Loci of Munsell constant-hue and constant-chroma for value 5/ in CIE (*x, y*)-coordinates for Source *C*.

If our color rendition problems could all concern the appearance of samples under light sources that differ in spectral distribution but are all a match in color for Source *C*, we might be able to solve them in a reasonably straightforward manner. For Source *C* we have a Munsell network worked out, so that a method is available for obtaining color specifications for the appearance of a sample under any number of light sources, just so long as they have the color of *C*. No problem of adaptation to the color of the light source would be involved since the adaptation would be the same for each source. There would, of course, be the problem of adaptation to any change in background color, but for the moment let us assume that this is neutral and held constant.

An example will serve to illustrate what is meant. For several years a subcommittee of this society has been working on the problem of color rendition of light sources, and as test objects they have included 18 Munsell 6/ value papers selected by Barr, Clark, and Hessler[15] for studies reported in 1952. Among

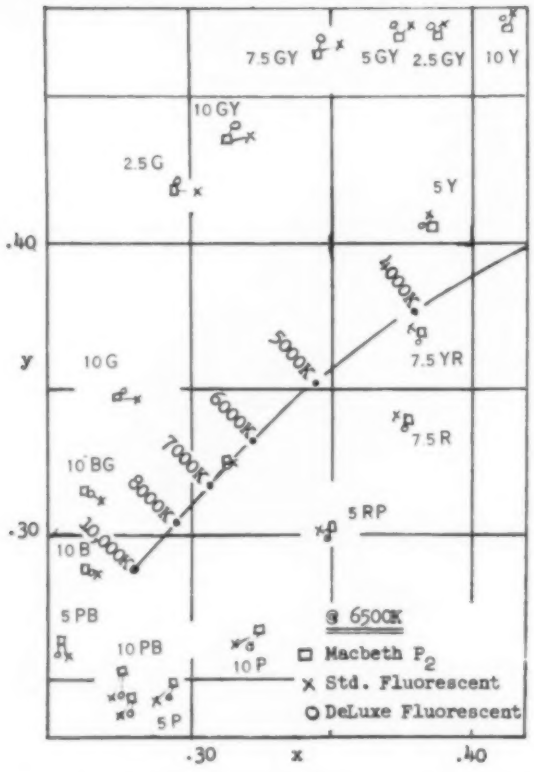

Figure 5. Color rendition of light sources: 18 Munsell samples for three light sources that are the same daylight color (6500K). This illustrates the color difference in samples caused by a difference in spectral distribution of light source.

the light sources used in the subcommittee's tests are three that are color matched in the daylight range. The spectral reflectances of the 18 samples were used to compute chromaticity coordinates according to the CIE Standard Observer for the spectroradiometric distributions of each of the three test sources. The light sources used were an incandescent lamp with Macbeth P_2 filter (Corning No. 5900), a standard fluorescent lamp, and a deluxe fluorescent lamp, all specially made to color-match at 6500K. The results are plotted on a CIE (x, y)-diagram in Fig. 5.

Since the samples are the same, and the color of the light sources is the same, the differences in color are due to differences in the spectroradiometric curves of the three light sources. The points representing the color of the light sources fall close to the Planckian locus between the points marked 6000K and 7000K. For purposes of illustration let us assume they are a close match for Source C so that we can read off the Munsell notations from the standard diagram for 6/ value (similar to the 5/ value diagram illustrated in Fig. 4). (Actually the 6500K light sources are slightly yellower than C, about 0.25 chroma steps on the C diagram, so that the notations will not be as accurate as if the three light sources were precisely at the C point.)

The resulting color differences are listed in Table II in terms of hue, value, and chroma differences, ΔE_N (a number representing the total color difference),[16] and an arbitrary number representing the distance on the (x, y)-diagram between the point

TABLE II — Color Differences Between Color Rendition of 18 Samples Under a Standard Lamp (Incandescent-Plus-Macbeth P_2 Filter) and Under Two Fluorescent Lamps, Deluxe and Standard, All Three Lamps Color-Matched at 6500K.

Color Sample Munsell Notation	No.	Δ Hue		Δ Value		Δ Chroma		ΔE_N		Deluxe Std. (x, y)-distance	
		Deluxe	Std.	Deluxe	Std.	Deluxe	Std.	Deluxe	Std.		
5 Y 6/4	1	+0.5	+1.0	0	0	0	+0.1	0.9	2.1	15	35
10 Y 6/6	2	+0.5	+0.5	0	+0.1	+0.1	+0.2	1.8	2.7	30	40
2.5 GY 6/6	3	+0.5	0	+0.1	+0.1	+0.1	+0.2	2.3	1.2	30	40
5 GY 6/8	4	+0.3	−0.2	0	0	+0.2	+0.2	1.4	1.2	40	45
7.5 GY 6/6	5	0	−0.5	0	0	+0.2	0	0.6	1.5	40	60
10 GY 6/6	6	−0.3	−0.9	0	0	+0.2	−0.2	1.4	3.1	45	65
2.5 G 6/6	7	−0.3	−1.2	0	−0.1	+0.1	−0.6	1.1	5.8	20	70
10 G 6/4	8	−0.6	−0.9	0	0	0	−0.5	1.0	2.9	20	55
10 BG 6/4	9	0	+1.0	0	−0.1	−0.1	−0.4	0.3	3.2	15	45
10 B 6/4	10	+0.5	+1.5	0	0	−0.1	−0.4	1.0	2.7	10	35
5 PB 6/8	11	+1.0	+1.5	0	0	−0.2	+0.2	2.8	3.9	30	40
10 PB 6/8	12	+0.5	0	0	0	+0.9	+1.0	4.0	3.0	55	65
2.5 P 6/8	13	0	−0.5	0	0	+0.5	+0.5	1.5	3.1	40	50
5 P 6/8	14	−0.3	−1.0	0	0	+0.5	+0.5	2.4	4.5	40	60
10 P 6/8	15	−0.5	−0.5	0	−0.1	+0.4	0	2.6	4.8	40	75
5 RP 6/6	16	−1.0	−1.0	0	−0.1	+0.1	−0.3	2.3	3.5	25	35
7.5 R 6/4	17	−0.5	+2.0	0	0	0	−0.4	0.8	4.4	15	35
7.5 YR 6/4	18	−0.5	+1.5	0	0	0	−0.1	0.7	2.4	15	25
Avg Diff.		0.4	0.9	0.0	0.0[2]	0.2	0.3	1.6	3.1	29	48

[1] ΔE_N = 1936 Nickerson "Index of Fading" = (C/5) $(2\Delta H) + 6\Delta V + 3\Delta C$.
This is a single number measure for color difference that is based on equivalence (for average viewing conditions) of 3 hue steps (at /5 chroma) to 1 value step, to 2 chroma steps. For special conditions the weighting for value may be varied.
[2] Arbitrary units.

representing each sample under the standard lamp and the points under the deluxe and standard fluorescent lamp. While the color differences are small (because at this high color temperature the spectral differences between the lamps are at a minimum), it is clear that the average color rendition of these samples for the deluxe fluorescent lamp is closer to that of the standard (incandescent-plus-filter) lamp than is the average color rendition under the standard fluorescent lamp. This is true whether we compare the hue, value, or chroma differences, the total differences, or the differences measured by distance on the (x, y)-diagram. If we had a diagram of truly uniform spacing, we should expect, if all necessary factors are taken into consideration, that the distances measured on it should correlate well with the perceived differences in chromaticness. Meanwhile, we use the Munsell notation, as read from the diagrams, to give us the best and most practical approximation we know how to get.

What can be done when light sources are not the color of daylight?

For the same 18 samples your subcommittee has worked with two other groups of light sources, each containing three lamps. One group was color-matched at 3000K, and the other at 4500K. In each group there is a standard lamp (incandescent for 3000K, filtered-incandescent for 4500K) and two fluorescent lamps, standard and deluxe. Computations and observations have been made for all conditions. Relative energy curves for the three groups of light sources are shown in Fig. 6. (This paper is not intended as a report of this work, but as a means of clarifying for others interested in problems of color rendition some of the problems that face the subcommittee.)

If we were able to transfer the Munsell network for Source *C* to the standard sources at 3000K and at 4500K so that it would provide the same spacing of colors that we have in daylight, we could then read off the colors in terms of their daylight appearance, and compare the color rendition of samples under one light source with that under another. This includes the problem of adaptation. But we have no way of doing this yet. The work of Helson[17,18] and Burnham[19,20] and their coworkers is providing a beginning toward this, but unfortunately it still looks as if we are a long way from being able to transfer the Munsell network to light sources of other chromaticities.

How then is it possible to put together the data for these different levels of color so that the internal results for each set may be compared with the internal results for the others? The matter is put this way in order still to avoid the problem of adaptation, a problem that must be faced when results are compared under light sources that differ in chromaticity.

Colorimetric results for the 18 samples, under

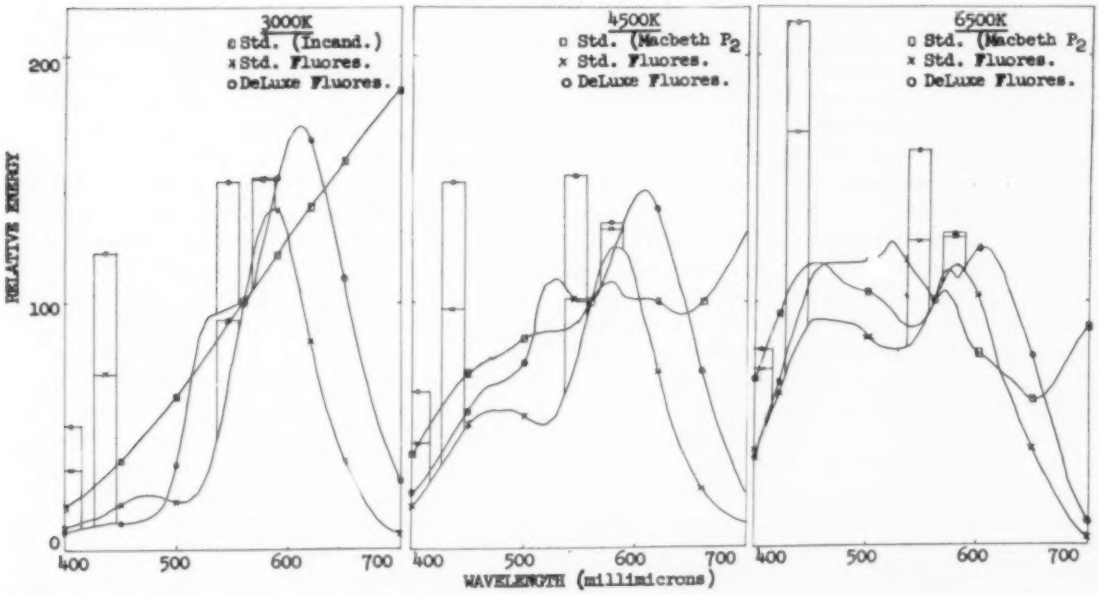

Figure 6. Relative spectral energy curves, adjusted to 100 at 560 mμ, for triads of lamps at 3000K, 4500K, and 6500K. In each group the squares refer to the standard lamp, crosses to standard fluorescent lamps; open circles to deluxe lamps.

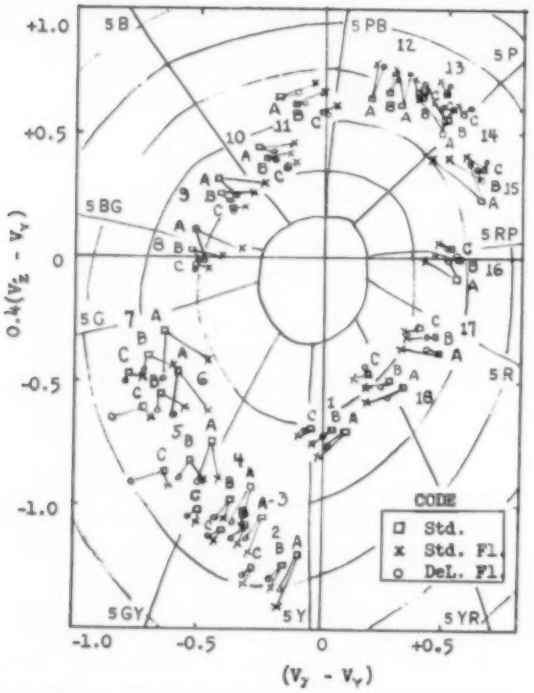

Figure 7. 18 Munsell samples, each calculated for 3 triads of light sources. These are plotted against a Munsell renotation network of hue and chroma on the Adams' Chromatic-Value Diagram to illustrate the relative size and direction of color change caused by change in light source. Code: Group A, at 3000K; Group B, at 4500K; Group C, at 6500K.

three triads of light sources, have been computed and plotted on as many types of diagrams as seemed promising. The only one on which all of the data could be assembled at one time so that some sort of comparison could be made between the results for each group, is the Adams' Chromatic-Value Diagram. All of these data are shown in Fig. 7, a Munsell Renotation Diagram for 6/ (the value of the samples used as test objects), superimposed on the Adams' diagram. From the data on this diagram it is evident that the color differences under the group of lamps at 3000K are much larger than those under 4500K, and that these in turn are larger than those under 6500K. The relative amount, and the direction of change within groups can be compared for similarities and differences. We have no way at present of knowing how the groups should be displaced to account for adaptation to the several light sources, although a correction for adaptation is made by the very use of the von Kries type of transformation that places the light source always at (0, 0) on the Adams' diagram. While it does not agree with all the facts

TABLE III — Color Difference (ΔE_N) on 18 Samples.

Color Sample		ΔE_N between					
		3000K Std vs		4500K Std vs		6500K Std vs	
		Fluorescent					
Munsell Notation	No.	Deluxe	Std.	Deluxe	Std.	Deluxe	Std.
5 Y 6/4	1	4.0	6.7	1.8	4.4	2.3	4.3
10 Y 6/6	2	7.4	8.8	3.3	4.5	2.4	3.3
2.5 GY 6/6	3	5.9	4.9	3.1	2.1	4.0	2.9
5 GY 6/8	4	4.7	5.0	2.4	3.6	2.3	0.9
7.5 GY 6/6	5	6.1	7.8	2.1	3.3	3.0	3.1
10 GY 6/6	6	6.9	8.9	3.6	6.0	4.6	2.9
2.5 G 6/6	7	6.6	11.8	3.0	5.4	1.9	3.1
10 G 6/4	8	10.4	10.0	3.5	4.8	0.8	2.0
10 BG 6/4	9	3.7	11.6	3.1	7.7	1.1	3.6
10 B 6/4	10	4.5	10.0	2.3	6.3	0.3	1.8
5 PB 6/8	11	4.6	9.0	1.4	6.9	1.3	3.4
10 PB 6/8	12	5.1	6.4	3.0	3.0	2.2	0.9
2.5 P 6/8	13	9.3	9.9	2.1	6.0	2.6	4.3
5 P 6/8	14	10.0	15.9	3.9	9.6	0.6	5.2
10 P 6/8	15	14.6	22.8	4.2	12.5	2.1	6.4
5 RP 6/6	16	7.4	11.2	0.6	4.1	1.2	3.3
7.5 R 6/4	17	3.2	11.0	2.9	8.0	0	0
7.5 YR 6/4	18	3.7	8.9	1.8	6.4	0.6	1.1
Average		6.6	10.0	2.8	5.8	1.9	3.0

that eventually must be taken into consideration, nevertheless for computing *differences* we can make use of the Munsell network on this Adams diagram and read off the notations and calculate them in terms of ΔE_N. This has been done for the group of lamps at each color level. The results, shown in Table III, provide a preliminary sort of color rendition rating for the several light sources by the size of the average color difference for the 18 samples seen under them. (The Source *C* data for ΔE_N in Table III differ from the data for ΔE_N in Table II because there is a difference in the standard lamp to which each is compared.)

This suggested use of the Adams' diagram is not intended as a final proposal, but it does point the way to the sort of thing that it should be possible some day to do with accuracy and with precision. Some way must be found to pull all the data together, preferably to show their relation to the separate factors of Munsell hue, value, and chroma, as well as to the size of the total color difference.

The Adams' diagram, for those who are not familiar with it, requires the use of CIE data for X, Y, Z. After adjustment so that $X = Y = Z$ for the light source (essentially an adjustment for adaptation), the data are then converted to V_x, V_y, V_z by use of the Munsell value scale. $(V_x - V_y)$ is plotted against $0.4(V_z - V_y)$. Since Y carries all of the luminance, after its subtraction from the X and Z factors only the chromatic factors are left, and they are plotted against each other, the neutral series at the center (0, 0), reds in the direction of $+(V_x - V_y)$, greens in the $-$ direction, purple-blues in the direction of $+(V_z - V_y)$, and yellows in the $-$ direction. The calculations are simple to make, they require use of a table of the Munsell Value function and X, Y, Z data for the samples.

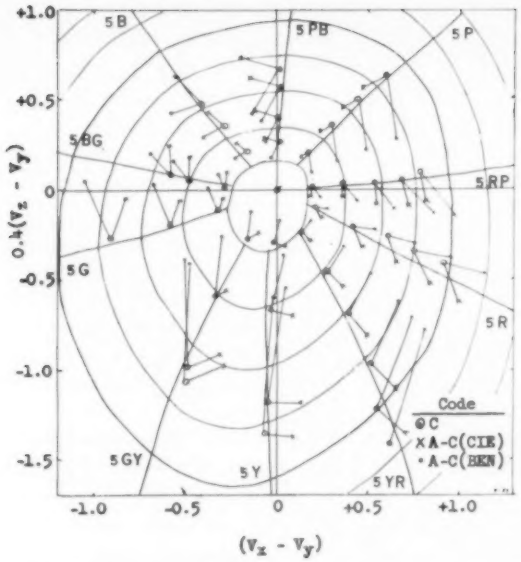

Figure 8. A series of Munsell samples (10 hues on 6/ value) as they plot on the Adams' diagram for Source *C* (circles), the same samples for Source *A* (crosses), and as calculated by the Judd prediction formula based on the Burnham data (solid points) for equal-appearing colors for Source *C* adaptation based on measurements for Source *A*. This illustrates, after conversion to the Adams' diagram, the size and direction of the color changes predicted by the Burnham studies versus those predicted on a basis of CIE primaries.

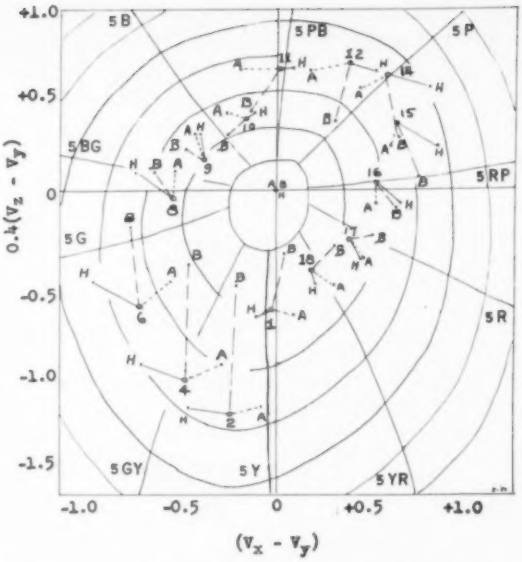

Figure 9. The effect of chromatic adaptation under Source *A* that is predicted in terms of Source *C* by formulas based on three sets of primaries, numbered 1 to 3 in the text, is shown on an Adams' Chromatic-Value Diagram: A (CIE) refers to (1), H (Helson) to (2), and B (Burnham) to (3). Circled points represent the *C* color of each sample; Munsell notations for the sample numbers are listed in Table II; N 6/ is at the center by all three formulas.

This same diagram allows one to study the Helson and Burnham results. In fact, it is possible in paired diagrams to plot the calculated and the observed data, and then compare them to see the extent of the differences between the two methods. This has been done for the Helson data since CIE data already were available[21] for the samples and light sources used in his most recent study.[18] Unfortunately, the scatter of the observations is so great that it is hard to find the pattern, but the data serve for reference involving other observational data. The Burnham results, by use of the prediction formula reported[20] for equal-appearing color with adaptation to Source *C* when the Source *A* color is known, were worked out for the basic series of 420 Munsell samples. However, the illuminants used in the Burnham-Evans-Newhall work were not precisely *A* and *C*, in fact Burnham's approximation to *C* was different enough so that N 6/, instead of reading 0 chroma as it does under CIE$_C$, read almost /2 chroma. Since Judd had worked out some months ago reversible formulas based on the Burnham-Evans-Newhall data that could be applied to light sources other than the precise ones used in making the observations, this Judd *A*-to-*C* formula was applied to Munsell 6 value samples. The results for this formula and for the CIE *A* to *C* conversion are shown in Figure 8, with lines connecting each of the results to the *C* color for each sample.

The communication in which Dr. Judd supplied the formula used for the foregoing conversion also provided similar formulas for two additional sets of primaries, making three in all:

(1) CIE primaries (used in the Adams' chromatic value space).

(2) Judd-Wyszecki primaries (which fit the Helson data and some of the MacAdam[22] data on chromatic adaptation).

(3) Brewer primaries (which fit the Burnham, Evans, Newhall data on chromatic adaptation).

Primaries	From *A* to *C*	From *C* to *A*
(1)	$X'=0.892X$ $Y'=1.000Y$ $Z'=3.321Z$	$X'=1.121X$ $Y'=1.000Y$ $Z'=0.301Z$
(2)	$X'=1.155X-0.457Y+0.476Z$ $Y'=1.000Y$ $Z'=3.321Z$	$X'=0.866X+0.396Y-0.124Z$ $Y'=1.000Y$ $Z'=0.301Z$
(3)	$X'=1.092X-0.272Y+0.149Z$ $Y'=1.000Y$ $Z'=-0.284X+0.839Y+1.835Z$	$X'=0.896X+0.306Y-0.073Z$ $Y'=1.000Y$ $Z'=0.139X-0.410Y+0.534Z$

Since these three formulas cover much of the work for which there is any considerable systematic

body of observational data, all three have been applied to converting CIE *A* data to terms of *C* for 14 of the samples used in the subcommittee work, plus N 6/. The results indicate the effect of chromatic adaptation under CIE Source *A* compared to CIE Source *C* that is predicted on the basis of the three sets of primaries named. In Figure 9 lines connect to the *C* point for each sample, the points that represent the color of each sample under *A*. These lines represent predicted color shifts.

As can be seen, there seems to be considerable difference in the predictions, depending upon the primaries used, the choice of primaries perhaps depending in turn on the conditions of the experiment. These predicted color shifts are much larger than the color distortions shown in Figure 7 where they are due to changes caused only by spectral differences among commonly used light sources. We know that adaptation results in a shift in the color of many objects, and while we know from a study of this last figure that the formulas here seem to provide results that differ considerably, they do make us hopeful that before too long we shall be able to find a formula that for specified background conditions will predict correctly the daylight color of objects that we see in our living rooms at night under incandescent light. Once a formula will provide this, then ways can be worked out to apply it to illuminants other than *A* and *C*. At present, we still do not know just what formula to use in order to calculate the daylight color of objects seen under tungsten — or other — light sources.

What Is Needed?

Eventually we must have a network representing uniform spacing that can be applied to whatever light source is of interest, one in which the relation between calculated and observed data is satisfactory for standardized conditions. We need a designation (such as the CIE) that can be calculated from measured data, and a designation (such as the Munsell) that will represent the appearance of a color, with some method by which these two can be converted from one to the other for any light source, sample, observer, and background.

As a practical matter we need to have computations for the basic Munsell series for whatever light sources are of most current interest, and we need to have these based on careful spectroradiometric measurements that will represent the average of lamps that are, or can be made available for observation. The eye sees very small differences, and is very critical. It is therefore important that observations and calculations be based on the same conditions, not just *nearly* the same. More work of the sort being done by Helson and Burnham is needed, not isolated studies, but studies precise and well planned, with all of the basic data and materials easily available for others to use (as has been the case with these workers). On the basis of such observations a Judd or a Brewer may find for us equations that will apply to the general, as well as the specific situation.

To date, while we may know the basic principles involved, and have data for a few conditions, we do not have sufficient data to solve the very practical problem of the illuminating engineer — the prediction of color appearance when one walks into a room and becomes well adapted to any one of the present-day light sources that differs from daylight. To solve this problem of the illuminating engineer, colorimetry enters a new phase, one in which the light source replaces the object as the important variable.

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DISCUSSION

C. N. CLARK:* Congratulations to Miss Nickerson for an excellent, highly readable and comprehensive paper. As indicated in the first part, choice of a standard source presents many problems. In general, standard sources appear to be chosen primarily so as to provide familiar color rendition, by being spectrally similar to commonly used natural or artificial sources, but with compromises as necessary for practical use in test work. Thus, it is logical to accept as formal standards Planckian radiators to 6000 K, and Abbot-Gibson daylight at higher color temperatures.

There are two drawbacks to these standards, as well as the series B standards mentioned in the paper:

(1) They cannot be made to match test source chromaticities that differ very much from the Planckian locus (such as mercury lamps or soft white fluorescent lamps).

(2) Their energy curves are "bumpy" in the higher color temperature range. Thus a test source with a smooth energy curve (logically a better color rendering source than the "bumpy" standard) would, by most rating systems, be unfairly penalized because it differed from the standard source. This difficulty stems from the fact that the standard source may not be the "best possible" or "ideal" source for color rendering. Of course, there are various opinions of what the ideal source might be, and of the criteria for selecting or defining such a source.

It is difficult to evaluate how serious these two drawbacks may be. Quite possibly they are not significant for today's practical sources. However, there may be a way to find the ideal source for use as a formal standard. Actually, it would be a *series* of ideal sources, one for each possible test source chromaticity in the white area, *on or off* the Planckian locus. It might be determined thus:

First, assume that there is such an ideal source at each chromaticity point (and thus for each possible state of color adaptation, assuming that the observer always adapts to the source color).

Second, assume that each ideal source should provide maximum perceived color separation (maximum color contrast) of a wide gamut of colors lighted by it.

Third, at each of a variety of source chromaticities, find the spectral energy distribution that yields maximum perceived color separation of a set of appropriately selected test object colors. This might be done by using a high speed data processing machine. The procedure would be to systematically vary the energy distribution of sources of constant chromaticity; calculate and average the color shifts of the test colors on a perceptually uniform (or nearly so) scale; and then pick, as the ideal source at that chromaticity, the energy distribution that gives maximum average contrast among the test colors.

Fourth, having done this for a variety of source chromaticities, derive a formula for ideal source spectral energy distribution at any chromaticity, as a function of chromaticity.

I have no idea what such "ideal" source curves may look like. At first thought, they may be similar to Planckian radiators. At any rate, such "ideal source" data, if possible to derive, could give us a better insight into the overall optimum source for seeing colors and color differences in general (that is, the source, regardless of chromaticity, that provides maximum object color separation, for an observer adapted to it), and a better baseline from which to measure the color rendition of practical sources.

The lack of a definite, proven "ideal source" is probably not too serious at this stage of the development of color rendition specification. Certainly, as Miss Nickerson has well stated, the need for continued work toward finding ways of expressing color appearance and color shift as they are perceived in the consciousness of a human observer, rather than in purely objective psychophysical terms, is of greatest importance.

D. B. JUDD:* The author is to be congratulated for a clear presentation of the factors that have to be considered in the development of a method for specifying the color-rendition properties of a light source. Considering its brevity the treatment is remarkably exhaustive, and the treatment is made concrete with little additional space by including the results of computations plotted on the Adams chromatic-value diagram (Figs. 7 and 8). Note that Fig. 7 shows the computed chromaticities of all 18 Munsell samples for each of the 9 sources studied. The author points out that the chromaticity differences computed for any given sample caused by changing from one source to another of the same chromaticity (such as from standard warm-white to de-luxe warm-white), are correctly shown on this plot, and properly warns us that any interpretation of differences from one group of sources to another would be unwarranted because "we have no way of knowing how the groups should be displaced to account for adaptation to the several light sources." It may be worth while to point out that the "v. Kries type of transformation" built into the Adams chromatic-value diagram is almost certainly wrong because the primaries of the transformation (those of the CIE system) are far outside the range of permissible primaries found by recent studies of chromatic adaptation by Helson,[18] Burnham,[19,20] and MacAdam.[22] These three studies do not agree well, and MacAdam's work, in particular, suggests that no single v. Kries type of transformation, regardless of choice of primaries, can accord precisely with the facts; but the coordinate systems supported by any of these recent studies afford a closer approximation than that yielded by the Adams chromatic-value diagram. The use of this diagram in Fig. 8 with the network of constant Munsell hue lines and constant Munsell chroma lines is still very helpful as long as it is realized that the crosses representing computations for Source *A* are already adjusted to take approximate account of adaptation. Thus if the tri-stimulus values, X_a, Y_a, Z_a, are found by computation for a sample illuminated by Source *A*, the very first step in computing chromatic values, V_x, V_y, V_z, is to find the ratios:

$$X_a/(X_a)_{MgO},\ Y_a/(Y_a)_{MgO},\ Z_a/(Z_a)_{MgO}$$

and it is obvious that these ratios will all be unity if the sample is the magnesium-oxide reflectance standard. This accords with the experimental fact that a white surface like MgO, illuminated by a nondaylight source still is judged because of adaptation to appear approximately white. The use of these ratios is a "v. Kries type of transformation" spoken of by the author; but, since the primaries referred to (the CIE primaries) are known to be inapplicable, in general, for an account of the facts of chromatic adaptation, the points (shown as crosses in Fig. 8) give an increasingly poorer approximation to the facts as the chroma of the sample departs more and more from zero. Compare the points (shown as dots on Fig. 8), located by the Burnham prediction formula with the crosses for each sample in turn. Note that the distance between each two such points increases regularly with chroma. The dots give a more reliable indication of the influence of adaptation to source

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TABLE A — Color distortions introduced by the Deluxe daylight fluorescent lamp relative to those introduced by the Standard daylight fluorescent lamp.

Munsell Notation of Color Sample	$100\,\Delta E_N$ (Deluxe) / ΔE_N (Standard)	$100\,D$ (Deluxe) / D (Standard)
5 Y 6/4	43	43
10 Y 6/6	67	75
2.5 GY 6/6	192	75
5 GY 6/8	117	89
7.5 GY 6/6	40	67
10 GY 6/6	21	69
2.5 G 6/6	19	29
10 G 6/4	24	36
10 BG 6/4	9	33
10 B 6/4	37	29
5 PB 6/8	72	75
10 PB 6/8	133	85
2.5 P 6/8	48	80
5 P 6/8	53	67
10 P 6/8	54	53
5 RP 6/6	66	71
7.5 R 6/4	18	43
7.5 YR 6/4	29	60
Average	52	60

A than the crosses because they are founded upon actual experiment; the crosses are founded only upon the Adams theory of vision[23] whose latest form[24] carries implications regarding chromatic adaptation not supported by any of the presently available, rather widely divergent, sets of experimental data. Compare in Fig. 9 the *A*-vectors (CIE primaries) with the *H*- and *B*-vectors.

I have another comment relating to the simpler, and commercially more urgent, problem of specifying the color rendition of sources relative to a standard of the same chromaticity. This problem is simpler because no general chromatic adaptation is involved, and my comment relative to the number of test samples to be used in the specification and also to the desired color-rendition rating "whether one- or multi-numbered." Although she does not say so explicitly, the author has developed a logical basis for such a rating. This basis is the color distortion introduced by substituting the source to be rated for the standard against which it is rated; see the last four columns of Table II. The first pair of columns (headed ΔE_N) is a thoroughly defensible evaluation of color distortion; the latter pair of columns (headed (x,y)-distance) is a less defensible evaluation chiefly because distance on the (x,y)-diagram in a given region varies importantly in perceptual significance depending on direction. A second defect, minor for this group of test samples, is that (x,y)-distance is a measure simply of the chromatic aspect of the color distortion and neglects the lightness aspect of the distortion. The first row of entries in these four columns indicates that the color distortion, ΔE_N, introduced by the deluxe daylight fluorescent lamp is only $100 \times 0.9/2.1 = 43$ per cent of that introduced by the Standard daylight fluorescent lamp; and the chromatic distortion indicated by (x,y)-distance is likewise $100 \times 15/35 = 43$ per cent. The relative distortion (deluxe to standard) computed this way for all 18 test samples, is given in Table A.

If the 18 test samples used are accepted as a suitable choice for rating fluorescent lamps, either method of rating indicates that this particular deluxe daylight fluorescent lamp causes about half as much color distortion as this particular standard daylight fluorescent lamp. The approximate evaluation of color distortion by means of (x,y)-distance wrongly indicates that the deluxe rendition of each test sample is less distorted than that by the standard fluorescent lamp, but the precise evaluation of color distortion by means of the Nickerson formula indicates that for three of the test samples the deluxe rendition is poorer. The question raised is whether a rating based on the average distortion for a selection of test samples is sufficient for the lamp industry, or should the rating be multi-numbered so as to include the distortions introduced by the lamp for each of a number of individual test samples. Is it valuable to know that this particular deluxe lamp distorts colors in the green-yellow and the purple-blue range more than the standard fluorescent lamp? The subcommittee will have to come up with a good answer to this question.

References

23. Adams, E. Q.: "A Theory of Color Vision," *Psychol. Rev.*, 30, 56 (1923).

24. Adams, E. Q.: "*X-Z* planes in the 1931 ICI System of Colorimetry," *J. Opt. Soc. Amer.*, 32, 168 (1942).

GUNTER WYSZECKI:* Miss Nickerson's paper provides an excellent insight into the problems which are involved in the measurement and specification of color rendition properties of light sources. In particular, the paper shows very clearly the importance of the choice of reference lamps and discusses various methods of interpreting and subsequently measuring color rendition properties of light sources. The major problem, however, which makes a completely general solution difficult, turns out to be the effect of the chromatic adaptation of the eye. By changing from one light source to another of a different chromaticity, the state of chromatic adaptation of the eye is changing in a way which, so far, cannot be described adequately in quantitative terms.

The work of the IES Subcommittee on Color Rendition is mentioned and their present results are essentially included in the paper. It may, however, be of general interest to mention two other aspects of the color rendition problem not being discussed in the paper, although they are being considered by the subcommittee. One aspect is the psychological phenomenon, the color preference problem. It is known that, for example, the quality of food is often judged by its color and that good quality food does not necessarily have to show its natural color, but preferably a slightly different shade in order to appeal to the consumer. It is admitted that a quantitative consideration of color shifts with respect to color preference makes the specification of color rendition extremely difficult, but it is believed that in some practical cases this psychological factor may have an important bearing on the usefulness of a potential solution of the problem.

The second aspect is the choice of a reference sample which should be made when developing a specification method. The subcommittee so far is studying 18 Munsell paint samples providing an approximately uniform hue circuit at value 5/. Properly measured color shifts observed on those samples by going from one light source to another will essentially be used to derive a method to specify the color rendition properties of a light source with respect to a standard. The question remains whether these 18 Munsell paint samples are an adequate choice for most specification problems, since it is very likely that in general, other materials of different spectral characteristics will be illuminated by the light sources to be specified. It therefore is believed that the inclusion of reference colors which are metameric to the given set of colors with respect to the standard source and the standard observer will provide a more general solution of the problem.

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CHARLES W. JEROME:* Since I am a member of the committee whose work is described in this paper I can only corroborate the statements made by Miss Nickerson. I believe she has very lucidly described the crux of the problem and the many complexities which have been encountered in attempting to derive a solution.

I am glad that she can point out the considerable progress that has been made in this direction and can hold out hope that a workable solution will eventually be recommended.

ARTHUR M. WEEKS:** This paper presents the progress which has been made by the various committees with which Miss Nickerson has been associated. I congratulate the author on this paper, but more specifically on the long list of contributions which she has made to the science of color measurement.

The question I ask may seem unfair, but certainly it is of general interest to all concerned with the measurement of color, and particularly, color rendition.

Is it possible at this time, to place any sort of time table which will indicate when we may expect a number system of designation of color rendition?

DOROTHY NICKERSON:† Let me reply first to Mr. Clark's comments, for they concern the first section of the paper, then to comments by Dr. Judd, Dr. Wyszecki, Mr. Jerome and Mr. Weeks.

Mr. Clark points out that while it is logical to accept the suggestion that as a standard we use Planckian radiators to 6000K and curves for Abbot-Gibson for higher color temperatures, he finds two drawbacks to these standards as well as to series B.

I believe there are two lines of thought involved here; one is that for usual work with color, when one expects to obtain good color rendition, a set of reasonably smooth curves seems needed to represent the range of whites from the low color temperature yellowish whites to higher color temperature bluish whites. In my opinion, such curves should follow the pattern of daylight not only in the range of the visible wavelength but out into the ultraviolet and infrared, as far as they may be expected to have any appreciable effect upon perceived colors. For example, the question of extending the curve for *C* illuminant into the ultraviolet already has been raised within CIE committee (W-1.3.1), as it has been also in the work of the Inter-Society Color Council's subcommitte on Problem 18 (colorimetry of fluorescent materials). I do not consider the Abbot-Gibson too "bumpy," certainly these curves must reach a maximum in the blue and then fall off in energy as they approach the ultraviolet if they are to follow the energy distribution of daylight. Eventually we hope to extend these curves into the ultraviolet so that the color of fluorescent samples assessed by means of these data will provide an answer that will agree with the color seen in an average daylight situation for the same samples.

The fact that the Abbot-Gibson series cannot be made to match all test source chromaticities does not seem a valid objection, for no one-dimensional series of smooth spectro-radiometric curves can be expected to do this. If any single color or source is to be used as a standard for color rendition, then this would seem to be some sort of "average daylight." Abbot-Gibson at 7400K has been selected as a practical solution for this single standard. If a mercury lamp or a soft white fluorescent lamp is to be tested for color rendition, as Mr. Clark suggests, then the most simple test is to find out how much either lamp changes the "daylight color" of objects. If there should be a reason to test a lamp whose color lies off the Planckian locus to find out how different its color rendition is from a lamp of similar color, but one with a smooth continuous energy distribution, then a special curve could be set up for that particular situation.

The suggestion that there may be some one point in the range of whites, whether on or off the Planckian locus, that could by calculation be found to be an ideal source (by definition one that would provide a maximum separation of perceived colors for a wide gamut of color samples) is interesting, and I would like to see the answer. But if the specifications for such a source were found, and results under it differed from those under average daylight, then we would be faced with considerable confusion, both in practical color matching work now done in daylight and in current studies of uniform color spacing. To be practical such a light source would have to become so cheap and easy to use that it could compete with daylight as the most-used source for observing colors.

Meanwhile, for industries finding it necessary to specify lamps for use in color appraisal the data published here provide a useful standard. The 7400-7500K curve of Abbot-Gibson has been used since its development in 1940 as a standard to which the lighting of cotton classing rooms has been referred, and within the past year the graphic arts industry has made it a part of a new recommended lighting practice for their industry. (See I.E., September 1957.)

This subject of a standard concerns only one phase of the color rendition problem, but it is a very practical one for those who wish to adopt and use an artificial light source for their color appraisal work. Let us now turn to points raised on other phases of the color rendition work.

Dr. Judd's comments serve to amplify several points, and call attention to their importance. For example, few not familiar with the subject can realize what an important bridge was crossed in this color rendition work when a way was found to pull together in a single graph the results for many samples (spread over the hue circuit) each under as many as nine different illuminants. That is a lot of data, yet if a way is not found to pull it together so that the relative shifts can be seen at one time for a whole series of samples (eventually enough to provide good statistical representation for the most-used part of color space) under several different illuminants, then it will not be possible to understand the problem clearly. For committee work it is an absolute necessity that the data be presented in a way that the color relations may be clear to a group of busy men. As Dr. Judd points out, even now it is necessary to warn those who study these diagrams that we do not yet know how the data for results at different levels of illuminant color should be displaced in relation to each other. His discussion should be very helpful to those who want to get down to fundamentals on this.

In regard to Dr. Judd's next point, as my studies into this work have progressed, I am coming more and more to the point of view that already we have a simple way to find a single or a multi-numbered color rendition index, one that can be based on as many or as few samples as one wishes for any given situation.

Conversion of the color results, however they are first obtained, to an appearance specification in terms of Munsell hue, value or chroma will allow a study of the hue, value or chroma rendition properties of any lamp, and then on the basis of a suitable color difference formula, this could be

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†Author.

expressed in terms of a single number to cover the overall or average color rendition properties of a light source. Table II illustrates how this is possible.

It should be pointed out that while the "average" or "single-number" result by any other method than one based on uniform color space may sometimes provide an overall figure that agrees with an average for data based on uniform spacing, such a method can be very misleading when it is broken down. Dr. Judd's Table A shows this clearly, for while the "single number" for average results based on the Munsell evaluation is 52, and not too different from 60, which is based on the visually non-uniform space represented by the CIE (x,y) diagram, yet the differences for individual samples vary widely. Dr. Judd raises the question whether a rating based on the average distortion is sufficient for the lamp industry, or should it be multi-numbered so as to include the distortions for any part of color space in which one may be interested. My answer is that if we use the type of method illustrated in Table II we can have both, for in order to obtain a "single number" one already would have the multi-number data.

I should like to point out that Japanese workers Azuma and Mori already have suggested that color rendition results be expressed in terms of Munsell hue, value and chroma differences. My suggestion takes this one step further, and suggests totaling results by use of a color-difference formula as has been done in Tables II and III. It is my considered suggestion that all formulas be developed so that the color of any sample under any or all illuminants can be computed or converted into terms of its "daylight color" (for the present this would be to CIE *C*), it would then be possible to obtain a Munsell specification for this equivalent "daylight color." Thus already we have at hand an adequate method for a single or a multi-numbered rating of color rendition. To avoid confusion, it might be well to plot these results directly on a Munsell hue-chroma diagram, making note in numbers of the value change. (This too, Dr. Azuma and his co-workers have already done.)

However, it is only *if* or *when*, adequate formulas are developed for predicting the equivalent color in daylight (or *C*) for colors seen under a given set of standard conditions for such other illuminants as we may be studying, that it will be possible to complete such work. We know how to do it but we still need appropriate information of the Helson and Burnham type of visual studies before we can proceed to wrap up this phase of the work.

The points covered by Dr. Wyszecki are important. He recognizes the lack of information that is mentioned above, and seems to feel less optimistic than the writer about its solution in a not-too-distant future. The preference aspects of color rendition he mentions should be relatively easy to handle if one works on the basis just described, for individual data could be made available for as few or as many samples as needed, and in terms of whatever color factors are important in a given problem. If butter is to be illuminated, then certainly a light source should be used in which the color will not shift toward the green. To be satisfactory, our color rendition specification method must apply to special, as well as to general, cases of color rendition. Perhaps it would help to define these terms (as we have for CIE W-1.3.2) as follows:

COLOR RENDITION: Color rendition (color rendering property) of a light source is a measure of the degree to which the perceived colors of objects illuminated by the source conform to those of the same objects illuminated by a standard source, for specified viewing conditions. The usual conditions are that the observer shall have normal color vision and be adapted to the environment illuminated by each source in turn.

GENERAL COLOR RENDITION: Same as color rendition.

SPECIAL COLOR RENDITION: Same as color rendition, but restricted to a particular object (or a group of objects of which the particular object is an adequate representative).

To Dr. Wyszecki I would say that no magic is expected of the series of 18 samples being used by the I.E.S. Subcommittee on Color Rendition. They provide for reasonably good hue coverage, and were convenient as a starting point since Barr, Clark and Hessler already had used them in color rendition studies. Their limitation to a single reflectance level, an advantage at present, will have to be remedied for later studies. However, it should be pointed out that groceries, as well as papers, were used by the subcommittee in early tests, and were omitted later after it was found that the shifts recorded for them fell into line with those for the papers when the results were studied in hue order. Papers have the advantage that the same objects can be measured and observed. With groceries or complexions this is not always possible. To be adequate, any final proposal must take into consideration the shifts for colors found in all common situations, and at least some of those not so common.

I want to thank Mr. Jerome for his comments, and Mr. Weeks for his. As for the time table Mr. Weeks inquires about, I believe that the very organization and preparation of the material for this report and its discussion, plus the data requested by the IES subcommittee which is now being assembled for its next meeting, will be enough help in resolving questions about this work so that it should be possible to lay the matter clearly before the committee at its next meeting so that they may then be able to decide whether we should go ahead now on that part of the way we can see clearly, or whether we must wait until we can obtain sufficient information on which to go the whole way in providing a specification for color rendition.

I.E.S. Emblem

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INSTALLATION AT THE FAIR, OLD ORCHARD SHOPPING CENTER,
SKOKIE AND GOLF ROADS, SKOKIE, ILL.

Lighting a Department Store

LIGHTING OBJECTIVE: To provide general lighting and highlights from a fixed lighting system for displaying and selling various types of merchandise.

GENERAL INFORMATION: Merchandising is done on each of the three 36,000 square foot floors of this suburban department store (suburb of Chicago). The building design provides 20-foot by 20-foot bays on all of floors and ceiling heights of 10 and 11 feet. Colors and reflectances of the room surfaces are:

ceiling		
acoustical tile	light gray	75% RF
luminaire trim	white	85% RF
walls	gray	65% RF
columns	gray	65% RF
floor	buff	[illegible] RF

(over)

A.I.A. File No. 31

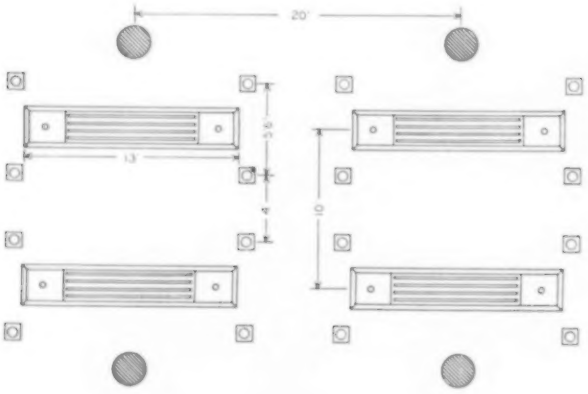

Figure 2 (left). Plan view of typical bay.

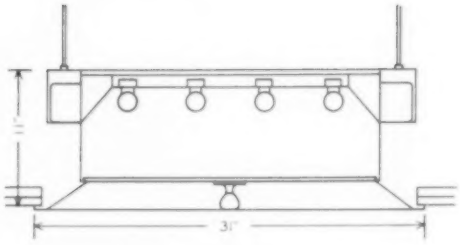

Figure 3 (above). Section through fluorescent luminaire.

INSTALLATION: General lighting is provided by two 31-inch by 13-foot recessed fluorescent luminaires (Solar Light Mfg. Co. catalog No. 33440) and eight recessed incandescent units (Solar catalog No. A 9953) per bay, located as shown in Fig. 2. The center 8 feet of each of the fluorescent units is equipped with a Honeylite aluminum louver panel and four 96-inch T-12, 800 ma rapid start deluxe warm white lamps (to secure the desired color rendition). The two end portions provide outlets for the sprinkler system. The entire unit is recessed approximately two inches into the ceiling (see Fig. 3) for the purpose of minimizing the appearance of the many sprinkler heads. The incandescent units are equipped with Alzak reflectors and 100-watt A-21 lamps.

All wall and floor cases are equipped with concealed local lighting for accent. Perimeter lighting (not shown above) is employed over wall cases for general effect and increased illumination.

After 1500 hours use, the average level of illumination in the merchandising areas was 60 footcandles. Brightnesses of the major fixed room surfaces at that time were:

luminaires	
fluorescent at 45°	400 fL
at 30°	300 fL
at 15°	175 fL
incandescent at 45°	30 fL
ceiling	15 fL
columns (at eye level)	30 fL
floor	30 fL

Lighting designed by J. W. Kiernan, Store Manager, The Fair, Skokie, Illinois, and Bernard Lazerson, Lighting Consultant, Chicago, Ill.

Lighting data submitted by Solar Light Manufacturing Co., 400 North Ashland Ave., Chicago, Ill., as an illustration of good lighting practice and to aid in the design of similar installations.

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Acoustics and Lighting

By GEORGE W. CLARK

THE GROWING importance of extended area lighting systems and the trend toward higher illumination levels at lower ceiling heights using recessed or surface mounted luminaires has made it necessary for the illuminating engineer to have a good understanding of acoustics in order better to promote good lighting. While our natural inclination may be to dismiss all acoustical design considerations as problems for the architect, consulting engineer, or acoustical engineer we cannot so readily divorce ourselves from the problem without losing much of the initiative in designing the lighting as well.

Until recently, the major acoustical concern of the lighting man was the problem of noisy fluorescent ballasts. Here for the first time he was faced with the term *decibels*. Without having to know exactly what a decibel is or how to apply it he can use the ballast manufacturers' ratings as a guide in the selection of equipment appropriate to a particular interior. Unfortunately, too many people including those in the lighting field, do not fully understand the rating system. Not realizing that each ballast type has its own particular and inherent range of noise levels, they expect to obtain each type in a variety of ratings. The author, and probably many others, feels that, helpful as they are, decibel ratings are fundamentally inadequate criteria for ballast noise quality standards. Since the real purpose of this paper is not to discuss ballast noise problems but rather architectural acoustics, we can dismiss the matter as having been the means of initiating the lighting engineer into the field of acoustics.

Just why have the higher levels of illumination and extended area lighting systems involved lighting people in acoustics? Basically, it is a matter of competition. In this case it is competition for the most obvious, and the most readily available room surface for acoustical treatment—the ceiling. This is not necessarily a new experience for those of us in the lighting business, since we've long had to compete for ceiling locations with the ceiling utilities such as air ducts and diffusers, sprinkler pipes and heads, etc. In most cases, however, this has not involved any substantial elimination of either lighting or other facilities but has rather been a matter of working out compromise positions for each. When our lighting systems actually eliminate area normally used for acoustical treatment the compromise becomes more basic and for that reason usually more difficult to resolve.

Unfortunately, it is generally the illuminating engineer with his limited knowledge of acoustics who is placed on the defensive by the architect, consulting engineer and/or owner. The introduction of extended area lighting systems, particularly wall-to-wall, undoubtedly brought the matter to a head since it occupies all or a major portion of the ceiling area and customarily eliminates use of acoustical ceilings over this area. Anyone associated with the design or application of such systems has faced the problem of answering questions regarding acoustics — questions which few representatives for acoustical materials are called upon to answer. Since it is the lighting man's product or lighting design which is considered the "culprit" it is he who must justify any reduction in acoustical treatment. Furthermore, he is not in the fortunate position of the acoustical ceilings man who can dismiss the problem by simply advising that the entire ceiling be covered with his product and that this will produce satisfactory results. If it were not that such acoustical materials provide a convenient means for finishing the ceiling or if the cost of such materials were so high as to raise the question of the necessity of full ceiling treatment, the acoustical representative would probably find himself in the the same position of justifying a recommendation; but at least he would be in his own field. Imagine the circumstance where the acoustical ceiling man is advising the architect, engineer, or owner that a certain quantity of luminaires will produce a given level of illumination and that this is adequate even if some illuminating engineer is advising higher levels. You then have the counterpart of the lighting man as he is called upon to give advice regarding acoustics.

Design nearly always is a result of compromise. Lighting and acoustics are no exception. In order

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 9-13, 1957, Atlanta, Ga. AUTHOR: Sylvania Electric Products Inc., Wheeling, W. Va.

to assure that the compromise represents a proper balance between the benefits of both, it would seem that the illuminating engineer must necessarily have some knowledge of acoustics where his lighting equipment is occupying space which would otherwise be acoustically treated.

It is unreasonable and fortunately unnecessary that the lighting man understand more than the architectural acoustics of rooms such as offices, schools, corridors, and lobbies. The highly involved theory of acoustics for auditorium, music rooms and electro-acoustic systems can thankfully be left to the expert, the acoustical consulting engineer. The practical aspects of acoustical treatment of general offices, however, should be appreciated by the illuminating engineer. As a graduate illuminating engineer, having taken no formal courses in acoustics, the author does not pretend to be a real expert in the matter. From experience, study and a more than ordinary interest in the subject he does feel qualified to interpret and summarize certain aspects of acoustics which he feels should be understood by the illuminating engineer. This is the purpose of the remainder of this paper.

There are two distinctive acoustical situations which must be treated in rooms such as offices. The first of these is treatment for sound absorption; the second is for sound isolation. Both are important and each involves the application of quite different acoustical principles. Let us begin with the former since it is the one most commonly thought of in connection with room acoustics.

Noise Reduction Coefficient

Today amongst most architects and engineers the first question which arises in any discussion of acoustics is "what is the NRC?" The reference is to the Noise Reduction Coefficient. To answer the question it is important to know what it *is*, but as will be shown later it is equally important to know what it *is not*. By definition it is the average, to the nearest multiple of 0.05, of the absorption coefficients at 250, 500, 1000, and 2000 cycles per second. The absorption coefficient in turn is a measure of the efficiency of a material to absorb acoustical energy at a given frequency. It is, therefore, similar to our concept of spectral reflectance except that it refers to absorption rather than reflection of energy. In addition to the frequencies mentioned above, absorption coefficients are normally reported for 125 cps and 4000 cps. (See Table I.) The nearest concept to the NRC in illumination is probably the common practice of using total reflectance as though it were independent of the spectral quality of the light source. While this is not technically correct, the error for high reflectance, low chroma, room finishes with "white" light is small and therefore does not seriously affect the usual illumination calculations. Apparently the same cannot be said of acoustical calculations using the NRC. It assumes that for all practical purposes the noise energy level in a room is equally distributed amongst the frequencies of 250, 500, 1000 and 2000 cps. The average room noise spectrum is quite different from this, having higher levels at the lower frequencies.

TABLE I — Typical Absorption Coefficients (α) and Noise Reduction Coefficients (NRC).

Description of Material	Absorption Coefficients (α) 125 cps	250 cps	500 cps	1000 cps	2000 cps	4000 cps	NRC
Luminous ceilings							
Acrylic plastic with rows of acoustic baffles 3' cc	.36	.25	.33	.31	.46	.36	.35
Vinyl plastic with no acoustic treatment	.22	.27	.18	.20	.11	.07	.20
Vinyl plastic with rows of acoustic baffles 3' cc	.28	.50	.23	.57	.21	.32	.40
Vinyl plastic with grid of acoustic baffles (3' x 4')	.36	.40	.46	.52	.53	.49	.50
Vinyl plastic double panel	.31	.28	.40	.27	.13	.07	.25
Vinyl plastic perforated and fibrous cellulose laminated	.34	.73	.72	.60	.67	.69	.70
Vinyl plastic with acoustical sub-ceiling	.62	.52	.50	.49	.33	.24	.45
Acoustical ceilings							
Acoustical plaster	.29	.36	.52	.65	.55	.49	.50
Metal pan, perforated, with mineral wool pad	.25	.58	.96	.97	.85	.72	.85
Vegetable fibertile, perforated	.14	.42	.99	.74	.60	.50	.70
Room surfaces							
Plaster walls	.04	.05	.06	.08	.04	.06	
Glass	.03		.03		.02		
Linoleum floor tile on concrete	.02		.03		.04		
Concrete slab ceiling	.01	.01	.02	.02	.02	.03	

The Noise Reduction Coefficient is the average value (to the nearest 0.05) of the absorption coefficients for 250, 500, 1000, and 2000 cycles per second. The absorption coefficients for acoustical ceilings vary greatly with type of mounting. Values given in this table are for commonly used methods of supports and are the basis for calculated data presented elsewhere in this paper.

Sources: Manufacturers published tests and Knudsen and Harris, "Acoustical Designing in Architecture," John Wiley & Sons Inc., New York, 1953.

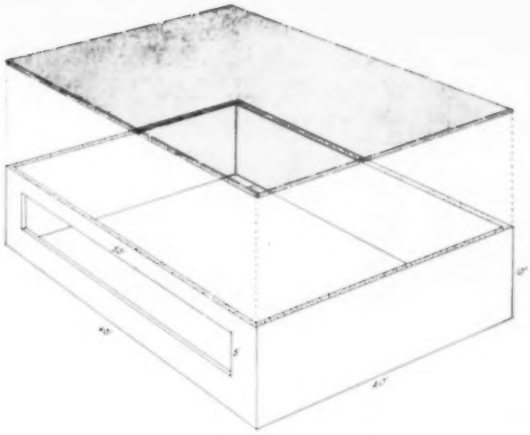

Figure 1. Schematic illustration of "typical office" used for lighting and acoustical calculations.

In order to calculate and demonstrate the significance of the NRC and various other related criteria we may assume a typical office as illustrated in Fig. 1. For the initial calculations, the walls are of plaster, the floor is linoleum tile on concrete, and there is a concrete structural ceiling. Furthermore, we select six typical combinations of lighting and acoustical systems as explained in Fig. 2. The lighting equipment includes suspended luminaires (A), recessed one-foot-wide troffers (B and C), two-foot-wide surface mounted luminaires (D), two-foot-wide recessed troffers (E), and a corrugated vinyl plastic wall-to-wall lighting system (F). The ceilings selected include sprayed acoustical plaster (A and C), perforated metal pan with mineral wool pad (B and D), perforated vegetable tile (E), and the luminous ceiling with perforated metal baffles filled with glass fiber and spaced in continuous rows three feet center-to-center.

The absorption coefficients and NRC's for all of these ceilings are given in Table I. They are further summarized by system letter in Table II. The absorption coefficients and NRC of acoustical ceilings vary greatly with the method and details of mounting. For example, one ceiling tile on the market has NRC ratings of 0.65, 0.70 and 0.80 depending upon how it is mounted. The suspensions for the ceilings selected for this paper are in common usage and the data shown in Table I are for these suspensions. To obtain the total absorption units provided by these various ceilings the total area of acoustical ceiling is multiplied by the NRC. In order to determine the effect, if any, of suspended louver fixtures on the NRC of an acoustical ceiling the author arranged for testing a typical louvered direct-indirect suspended (8-inch) luminaire.[1] The test results indicated no measurable "shadow" effect but do show a slight modification of frequency response. For System A, then, the absorption units are the ceiling NRC (.50) times the area (2400 square feet) giving a total of 1200 units. Recessed troffers and most surface mounted lumi-

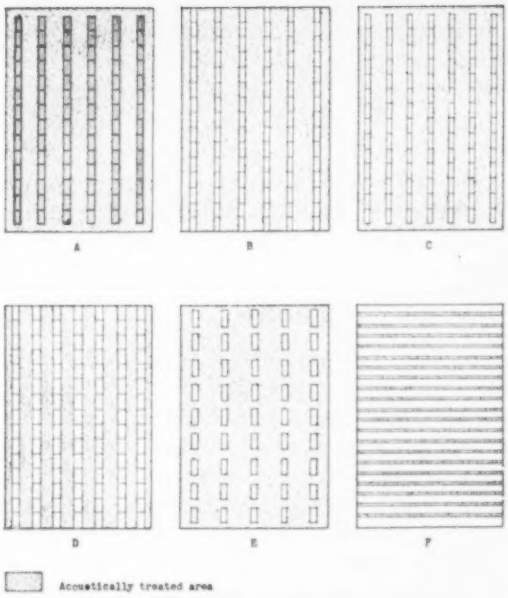

Figure 2. Six typical office lighting and acoustical systems. Assumed conditions: 40 ft x 60 ft office, 10 ft from floor to finished ceiling. Ceiling reflectance 75, wall reflectance 50. Plaster walls, glass window (area 5 ft x 50 ft), concrete structural ceiling, and linoleum tile on concrete floor. Illumination levels approximately 75 footcandles.

A. 2-lamp louvered suspended luminaire — acoustical plaster ceiling.
B. 2-lamp troffer with glass lens — perforated metal pan ceiling.
C. 2-lamp troffer with diffuse glass — acoustical plaster ceiling.
D. 2-lamp, wide, surface mounted luminaire with diffuse glass — perforated metal pan ceiling.
E. 4-lamp, wide, troffer with glass lens — vegetable fiber acoustical tile ceiling.
F. Vinyl plastic with rows of acoustical baffles 3 ft cc.

TABLE II — Acoustical Characteristics of the Six Lighting and Acoustical Systems Shown in Fig. 2.

Lighting and Acoustical System	Noise Reduction Coefficient	Noise Reduction (decibels)	Absorption Units	Loudness Reduction %
A	.50	7.7	1200	49
B	.85	9.2	1730	56
C	.50	6.9	1000	45
D	.85	8.2	1330	45
E	.70	8.4	1430	45
F	.40	6.8	960	42

naires either actually or effectively eliminate an area of acoustical ceiling. The results of this are evident in comparing the absorption units versus NRC for systems B through E.

Noise Reduction

Using these absorption units in conjunction with the absorption of all other surfaces in a room we can calculate a value called *noise-level reduction* or simply *noise reduction*. The formula is

$$\text{Noise reduction} = 10 \log_{10} \frac{\text{absorption after}}{\text{absorption before}}$$

The value obtained is in decibels. Noise reduction represents a concept foreign to the illumination field. Note the requirement for an absorption value before as well as after. For a new building the before conditions may have to be assumed (*e.g.*, the concrete structural ceiling of Fig. 1 is assumed as initial "finished" ceiling). Again drawing a parallel in illumination, the noise reduction would correspond to the *radiant* energy loss within a room with 70-40-14 surface reflectances compared with the same room having reflectances of 60-60-20 before painting. Noise reduction values have been calculated for each of the six systems and are shown in Table II.

All of the acoustical values so far discussed are purely physical in nature. In drawing comparisons from the field of illumination we have discussed only radiant energy concepts; we have not considered luminosity. Fig. 3 has been drawn to illustrate the parallel nature of light and noise. So far none of the acoustical terms have involved psychophysical concepts. Noise reduction coefficients, absorption coefficients, and absorption are merely properties of materials. The noise reduction in decibels has direct meaning only to a measuring instrument. In order to involve the ear and the mind there must be another term.

Loudness

The psycho-physical term which has been chosen for comparison in this paper is *loudness*. As shown in Fig. 3 loudness may be considered somewhat similar in concept to brightness. Loudness is generally measured in *sones*.

The *loudness reduction* calculations in this paper were made in accordance with the procedure outlined in Knudsen and Harris "Acoustical Designing in Architecture." The somewhat involved nature of these calculations may explain why there is so little evidence of the use of this value by architects and consulting engineers (other than acoustical consultants). As we know from our illumination experience, putting the human being into an "equation" always complicates it. Nonetheless, loudness reduction seems to represent much more nearly than any of the other values the element which in this instance we wish to control by the use of acoustical materials. It includes consideration of the noise spectrum in the room for which calculations are being made as well as the human judgment of loudness. Reference to Table II shows that there is very little direct correlation between loudness reduction and any of the other values. This is especially true of the most commonly used criterion for selecting acoustical material, the NRC. This is illustrated in Fig. 4.

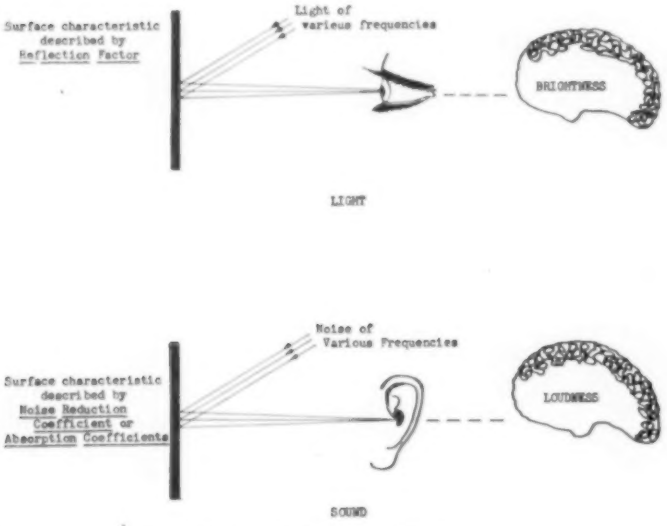

Figure 3. The parallel nature of *light* and *sound* as modified by light reflecting and sound absorbing surfaces.

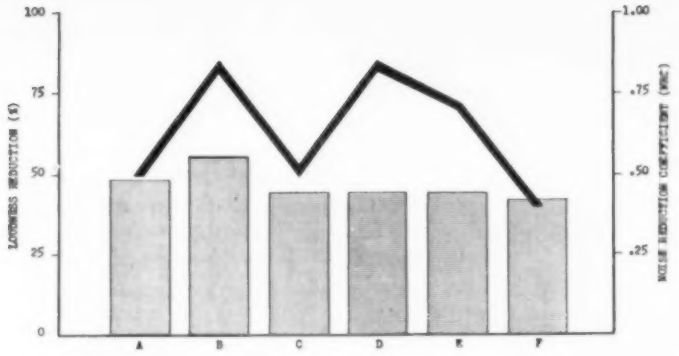

Figure 4. Graphical comparison of Noise Reduction Coefficient (broken line) and Loudness Reduction from data in Table II.

The complete explanation of this is beyond the scope of the present paper, but there are some aspects which should be understood. The use of the NRC ignores the fact that there is generally more low frequency noise than high frequency noise in the average office. The absorption of these lower frequencies is considered particularly important since they tend to substantially mask higher frequencies. The reverse is true to a much lesser degree. This fact makes the presence of lower frequency noises especially undesirable in an office due to their adverse effect on the ability to hear speech.

Standards for Acoustical Treatment Lacking

The question which now arises is just what noise reduction or loudness reduction is considered adequate. Before discussing this, however, it should be realized that the values shown in Table II are nearly *maximum*. The room conditions assumed as original provided little absorption. If it had been assumed that the floors were to be covered with carpets and the windows with draperies the noise reduction and loudness reduction achieved by the ceiling would have been substantially less.

In the opinion of the author, "official" criteria or standards for noise and loudness reduction in offices have not yet been established by the acoustical industry. This is not to say that work is not being done to achieve such standards. One of the most interesting efforts in this direction is the recently published paper of L. Beranek "Revised Criteria for Noise in Buildings"[2] in which he develops a series of *noise criteria* curves which in turn have been used as the basis of recommended standards for six categories of office. These categories relate to the nature of the work with respect to speech distances, telephone usage, etc. These criteria have been established with the aid of a statistically impressive subjective survey conducted by the Air Force. The fact remains, however, that the average architect and engineer does not have this information and if he did, it is not in a form conducive to his using it in his building design work. Instead, he leans, understandably, on the simple expedient of combining high NRC and full ceiling treatment for the average office, not being overly concerned as to whether this is too much or too little for proper acoustical treatment since (1) he must finish the entire ceiling anyway, and (2) it is usually impractical or undesirable to place acoustical materials on surfaces other than the ceiling. As Fig. 4 illustrates, if loudness reduction is accepted as the actual aim of the acoustical treatment, the NRC is not a particularly good basis for selecting an acoustical ceiling system. A luminous ceiling, with an NRC of 0.40 (System F) for example, provides essentially the same loudness reduction as a troffer installation with an acoustical ceiling having an NRC of 0.85 (System D). Furthermore, as Table II illustrates, there is a definite limit to the amount of reduction which can be achieved through ceiling treatment.

Reverberation Time

Reverberation time is also considered an important criteria of acoustical design. This is defined as the time for a specified sound pressure to drop to 1/1000th of its initial pressure. For general offices *optimum* reverberation times vary from 0.7 to 1.0 second depending on the volume of the room. The optimum for our "typical office" with its volume of 24,000 cubic feet is approximately 0.8 second. The following are the reverberation times calculated for the various lighting and acoustical systems:

System	A	B	C	D	E	F
Time — (sec.)	0.8	0.5	0.9	0.7	0.7	1.0
Variance from optimum	—	−0.3	0.1	−0.1	−0.1	0.2

In a larger room or a room with higher wall and floor absorption and occupied by people (approxi-

mately four absorption units for an adult) System F would come closer to the optimum while systems A, B, D and E would tend to depart further from optimum. If reverberation time were the sole criterion it would be acoustically desirable to apply acoustical materials over only a part of the ceiling in most large offices and many smaller offices having carpets, draperies, and other sound absorbing materials. Consider System D, for example, where only 65 per cent of the ceiling is acoustically treated. If the lighting of System A had been used to permit a full acoustical ceiling, the reverberation time would have been 0.4 second. In order to achieve the optimum of 0.8 second with this particular ceiling in our "typical office" it would be necessary to cover only 57 per cent of the ceiling. Since reverberation time is not the sole criterion, nor necessarily the most important, the above analysis should not be used alone as a basis of acoustical design.

Noise Isolation or Insulation

There is another phase of room acoustics which presents a design problem quite different from that which we have considered so far. It is that of noise isolation or insulation. Our previous concern has been with noise already within our "typical office." What about noise entering this office from outside or traveling from this office to another? With solid partitions to the structural ceiling, the ceiling has not been especially involved in the treatment of this particular problem. With the growing popularity of movable partitions extending only to the suspended ceiling, luminous ceilings and many newer acoustical ceilings by their very nature have proven inadequate to provide proper noise isolation. Both the plastic of luminous ceilings and the acoustical panels of many acoustical ceiling systems transmit sound very readily, permitting it to travel through the air space above the suspended ceiling, over the partition, and into the adjacent room. Where acoustical ceilings are used this is not a matter of responsibility for the illuminating engineer. When luminous ceilings are used, however, the lighting man should be in a position to advise specific treatment. A sound barrier such as that shown in Fig. 5 should be provided.

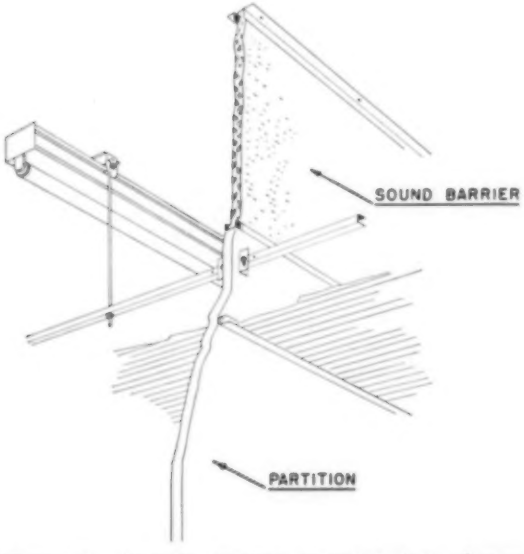

Figure 5. Acoustic barriers extended into plenum chamber of luminous ceiling as part of complete sound treatment when partitions do not extend to structural ceiling. Similar arrangements are necessary with many types of acoustical ceilings.

The effectiveness of a sound barrier is measured by its transmission coefficient. Sound absorbing materials generally make poor barriers, since by their porous nature they permit too great a transmission of sound. Barriers should therefore be constructed of heavy, solid materials. Some advantage can be gained by using double barriers provided they are isolated from one another in such a way as to prevent the vibration of one being effectively transmitted to the other.

Another principle that must be followed in establishing sound barriers is to avoid holes or cracks through which the sound can be transmitted. The transmission of sound through a hole or crack can easily equal that transmitted by one hundred times its area of sound barrier. Obviously, this then is a very important element in the design of a sound barrier system.

Conclusions

1. While today's higher levels of illumination and the growing importance of extended area lighting do place the illumination engineer in direct competition with the acoustical engineer for ceiling space, there seems to be no evidence at present that either one seriously jeopardizes the acoustical results, at least for the average office.

2. The NRC is not a realistic criterion for determining the value of an acoustical system. The loudness reduction of extended area lighting systems, for example, is comparable to most combined lighting and acoustical systems used in current practice in spite of its somewhat lower NRC.

3. The illuminating engineer should have sufficient knowledge of architectural acoustics to avoid unnecessary compromise of the benefits of good lighting, yet be able to recognize the importance of

a proper acoustical environment. By this means the illuminating engineer and the acoustical engineer can together best contribute to a total environment of which both can be proud.

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1. Special test by Richard N. Hamme of Geiger & Hamme, Consultants in Acoustics, Ann Arbor, Michigan.
2. Beranek, Leo L., "Revised Criteria for Noise in Buildings." *Noise Control*, Vol. 3, No. 1, January 1957, p. 25.

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DISCUSSION

D. E. SPENCER:* As the author has pointed out, the wide use of luminous ceilings has irrevocably involved the illuminating engineer in the field of acoustics. Whether he likes it or not, it is indispensable for him to be able to talk intelligently about the acoustical properties of the materials which he proposes to use on the ceiling.

As a supplement to Mr. Clark's paper, I would like to present some additional data on the acoustical properties of luminous ceiling materials, which have not previously been published, and to draw some conclusions from a comparison of some of these data with data given in the paper.

To fully characterize the diffusing plastic for the luminous ceiling, two characteristics should be measured: (1) acoustic transmission and (2) acoustic absorption. The data given in Figs. A and B and Table A were obtained by the Riverbank Acoustical Laboratories. The material tested is a vinyl diffusing plastic of the same type as that for which data are given in Mr. Clark's paper.

The acoustic transmission of the diffusing plastic as a function of frequency is plotted in Fig. A. It varies from over 0.80 at 125 hertz to 0.1 at 4000 hertz. The transmission can be expressed either as the per cent of the acoustic energy transmitted as shown on the left side of Fig. A, or as the sound transmission loss in decibels as shown on the right. At low frequencies, the sound transmission loss is only one decibel; at high frequencies, it becomes ten decibels. As averaged by the Riverbank Laboratories, the average transmission loss is four decibels, or an average acoustic transmission of about 40 per cent.

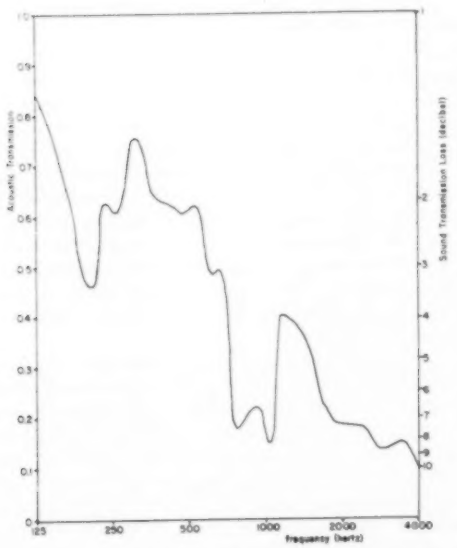
The energy which is not transmitted is either reflected into the reverberation chamber or absorbed by the diffusing plastic itself. So much sound is transmitted that the speaking voice can be heard with no appreciable attenuation through a vinyl plastic partition.

Thus, acoustic material placed behind the vinyl sheet does not entirely lose its effectiveness, for nearly half of the sound incident on the sheet is transmitted and can be absorbed by the acoustic ceiling. On the other hand, over half of the sound is reflected or absorbed by the plastic

TABLE A — Acoustic Absorption Data.

Material	Frequency (hertz)						Noise Reduction Coefficient
	125	250	500	1000	2000	4000	
Corrugated vinyl plastic	0.17	0.29	0.14	0.37	0.15	0.24	0.25
Plastic + Acoustic fins	0.25	0.42	0.36	0.57	0.44	0.48	0.45
Acoustic tile	0.30	0.52	0.84	0.82	0.67	0.56	0.70
Acoustic tile + Plastic	0.35	0.69	0.47	0.62	0.40	0.44	0.55
Acoustic tile + Plastic + Acoustic fins	0.52	0.72	0.63	0.79	0.59	0.51	0.70

*University of Connecticut, Storrs, Conn.



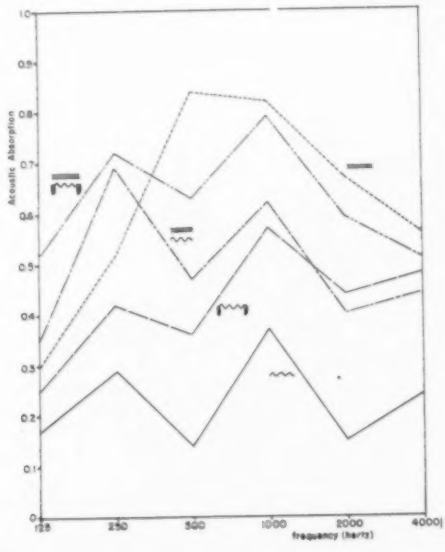


Figure A. (left) Acoustic transmission of the diffusing plastic as a function of frequency.
Figure B. (right) Measurements of acoustic absorption.

sheet. The reflected component may actually be useful in some cases in reinforcing sounds.

Measurements on acoustic absorption are given in Fig. B and Table A. Comparison with Table I of Mr. Clark's paper indicates that measurements of acoustic absorption are not reproducible with great accuracy. For similar vinyl plastic with no acoustic treatment, the values of NRC differ by 20 per cent. Five sets of measurements were made. In the first, the corrugated vinyl plastic was mounted on a normal suspension system in strips 3 feet wide and 8 feet long. Sound enters the plenum above the plastic only by transmission through the plastic or by penetration through the crevices at the edges of the supporting tracks. The test was then repeated with acoustic fins attached to the supporting tracks.

The acoustic material tested is a cellulose fiber tile of thickness 1-inch in 12-inch by 12-inch slabs, each weighing 0.96 pound. The distribution of holes was random with 313 holes per square foot. Each hole was $\frac{7}{32}$ inch in diameter and $\frac{23}{64}$ inch deep. The acoustic tile was painted white and mounted with #1 type mounting. This is considered equivalent to cementing the acoustic tile to a plaster or concrete ceiling. Three tests were made with this tile: tile alone, tile with plastic suspended below it, and finally, with acoustic fins added. The table also includes calculated values of the noise reduction coefficient, which is obtained by averaging the absorption coefficients at 250, 500, 1000 and 2000 hertz, and rounding the resulting average to the nearest integer multiple of five per cent.

A number of conclusions can be drawn from an examination of these data.

(1) Luminous ceilings can be installed below existing acoustic tile ceilings, but there are both acoustic and optical disadvantages. Below 500 hertz the acoustic absorption is actually improved by 5 to 15 per cent. Above this frequency, between 10 and 60 per cent of the sound incident on the luminous ceiling is transmitted and the absorption of the acoustic tile is reduced by about 15 per cent. If the NRC of acoustic tile was originally 0.70, it drops to 0.55 when the luminous ceiling is hung beneath it. As the optical reflectance of many acoustic materials is below 80 per cent, surprisingly large reductions in the coefficient of utilization may result.

(2) Acoustic fins can be compared with complete ceilings of acoustic tile. A corrugated vinyl plastic luminous ceiling with acoustic bars on three-foot centers is roughly equivalent to covering two-thirds of the ceiling with good acoustic tile. At 125 hertz, this ceiling has the same absorption as would be obtained if 84 per cent of the ceiling were covered with acoustic tile; at 250 hertz 81 per cent, at 500 hertz it drops to 43 per cent, at 1000 hertz is rises to 70 per cent, at 2000 hertz it is 66 per cent and at 4000 hertz, 86 per cent. If NRC are compared, the plastic plus acoustic fins is equivalent to covering 65 per cent of the ceiling with acoustic tile.

(3) The plastic used in luminous ceilings is of some acoustic value. The acoustic absorption produced by flexure of the panels varies from 14 to 37 per cent. The NRC is 25 per cent. A complete luminous ceiling is about as effective in acoustic absorption as covering one-third of the ceiling with acoustic tile. In the speech range, the plastic is a good reflector of sound and actually improves listening in an auditorium, classroom or conference room. At very high frequencies, the corrugations give improved diffusion of sound.

(4) Luminous ceilings without acoustic tile or acoustic baffles are justified in any room in which listening to sound is of great importance, such as an auditorium, lecture room or classroom. The reflective ceiling actually improves the distribution of sound over the room and enables people in the back seats to hear better. Necessary additional absorptive treatment should then be added in walls, floor and furniture.

(5) Wherever noise control is most important, acoustic baffles should be used, as in offices, lobbies, department stores and banks. Some supplementary acoustic treatment should also be employed in walls, in screens, furniture and floors, or above the luminous ceiling.

H. F. KINGSBURY:* In today's buildings and building systems, it would be hard to find a subject that deserves more attention than that of lighting and acoustics, unless it is air movement and acoustics. It is certainly timely that the author has made this contribution to better understanding of these fields.

In discussing the general application of acoustics to such types of spaces as offices and schools, the author has chosen a good starting point since the acoustical treatment of these spaces is frequently misunderstood and worthy of considerable attention. There are, however, a number of points that deserve emphasis in such a discussion of applied acoustics.

In the first place, the use of the noise reduction coefficient as a means of directly comparing the acoustic performance of several materials and designs is somewhat open to question, since the use of this rating gives but little information on the absorption efficiency of the material at the various frequencies which may be important. NRC is most valuable as a crude indication of the general efficiency of two different types of acoustic materials but should not, in general, be used as a sole basis of calculation of the effect of acoustic absorption in the particular space under question.

The author has assumed that the ceiling will, in most cases, be used for the application of acoustical treatment. While this is true for many offices and schools, it also develops that in many cases this is a less desirable location for the treatment, albeit the most convenient. Consider the case of the large, low-ceilinged classroom being built in many places today. Application of a good grade of acoustic treatment to the ceiling certainly will reduce the reverberation time in the room, and make it quiet or dead, in the sense that echoes are minor or absent, but what of the poor teacher who has to project her voice to the rear of this room, in spite of a good portion of the projected sound being absorbed by the ceiling. Actually, a far better acoustic treatment can frequently be done by applying absorption material to the upper inside and back wall of the classroom in less area than is used on the ceiling. If additional absorption is required, a limited amount, scattered on the ceiling will usually suffice and not produce difficulties with voice projection. The intelligent application of acoustic absorption can therefore help the architect, lighting engineer and the occupants.

Another factor that may be of importance for lighting engineers in the discussion of acoustics is the relative quiet of the area in which the equipment will be installed. For example, ballast hum would be no problem at all in an office where typing is done, with or without acoustic treatment. On the other hand, in an executive conference room in a quiet location, such as a suburban office building, ballast hum might be objectionable. Such factors should be taken into account in developing equipment specifications.

*Pittsburgh Corning Corp., Port Allegany, Pa.

There is another point on the application of absorption in noisy areas that deserves emphasis. Usually it is impossible to lower the noise level in an enclosed space by means of the application of acoustic absorption by more than six to nine decibels. Since the untrained human ear can seldom distinguish less than three decibels difference in sound pressure level, let the above emphasize that it is impossible, normally, to quiet a space in which noise is intruding from the outside by the application of absorption inside, even though the space may be made more acceptable by the reduction of random noise.

In the treatment of noise isolation, the importance of small holes in an otherwise acceptable partition cannot be too strongly emphasized. While the following illustration is not rigorously true, it nonetheless illustrates this point quite well.

A frequent type of office or school partition is one which has a sound reduction of 40 decibels. This type of partition allows a listener on one side, if his space is quiet, to hear a slight confused murmur from conversation occurring on the other side, but is in general not annoying. Assume for the moment that this partition is ten-feet by ten-feet or 100 square feet. Since the decibel scale is logarithmic, that is log to the base of 10 of the pressure, 40 decibels means a 10^4 or 10,000 fold reduction in the sound pressure through this wall. Now, what size hole through this wall will negate the effects of this wall? A little multiplication will show that it is of the order of one square inch in 100 square feet. In this wall how many switch boxes or convenience outlets are back to back? How big a crack is there between the partition and ceiling, or between conduits and the partition? These points illustrate why many otherwise well-designed jobs may bring acoustic complaints.

In summary, a better understanding of acoustics is needed by the lighting engineer, although not necessarily in the sense of how to make an undesirable space acceptable from an acoustic standpoint, but rather how his equipment and installation may affect the entire area, and how compromises may be effected between lighting and acoustics that will not work to the detriment of either.

R. N. HAMME:* In criticism of the exclusive use of the NRC as the criterion of relative merit between acoustical ceilings, the author draws mainly upon two observed facts: viz., the usual predominance of low-frequency noise components in the disturbance spectra commonly encountered in noise-control situations, and the greater importance of low-frequency noise in masking speech sounds. These factors in themselves conspire to give greater emphasis toward the attainment of low-frequency sound absorption, but they give little insight into the further possibility of relaxing the need for high-frequency absorption, which also turns out to be permissible, and indeed desirable in many applications.

The use of sound-absorbing materials inside a room constitutes only one of four techniques for palliative noise reduction, the sound absorption being the "last-ditch" defense in frequency ranges where vibration damping, vibration isolation, and airborne-sound isolation have failed. It can be shown[1] that each of the three latter techniques are most likely to break down in the low-frequency range, so that the boundaries of a room (or the enclosures for noise sources) are most likely to behave like low-pass noise filters, blocking the entry of high-frequency noise but permitting the entry and build-up of low frequency interfering sounds. The disturbance spectrum can therefore be expected to peak in the low-frequency range, and all the more so in situations where isolation treatment has been undertaken with care. The need for high-frequency absorptive treatment in the terminal environment may have been relaxed by clever peripheral treatment, but the low-frequency interference problem is likly to be relatively unaffected.

Compounding this fact are the characteristics of incidental sources of sound absorption in inhabited rooms. Since the noise reduction ultimately accomplished (no matter what the criterion of evaluation) depends on the ratio of the absorption-before to the absorption-after treatment, the frequency characteristics of the typical "absorption-before" situation must be scrutinized. The absorption characteristics of typical room contents: the draperies, the carpets, the people, even the air itself, are such that a profound deficiency of low-frequency absorption is the usual situation encountered; the sources of incidental absorption are mostly confined to the high-frequency range. From a noise-reduction standpoint there is then a great deal more to be gained from the introduction of a given amount of absorption at low frequencies as compared to high. From a room acoustics standpoint (reverberation control) there is usually a requirement for increased low-frequency absorption without a corresponding increase at high frequencies. Taken as a whole, then, the absorption-versus-frequency characteristic of the class of "luminous ceilings" represented in the author's Table I might better represent the typical absorption requirement, in practice, than do the class of "acoustical ceilings" listed in the same table. In contrast to the NRC, our tacit reference is to the ratio of the 125 cps and 4000 cps sound absorption coefficients.

1. R. N. Hamme: "Acoustical Materials Problems Posed by Low-Frequency Sound Control," *Noise Control*, Vol. II, No. 5, pp. 10-15, September 1956.

P. H. LAMSON:* Not many people will realize the amount of work which has gone into the preparation of this paper, especially in the calculations of loudness reduction.

I would like to call to the author's attention, an error in Table I.** The absorption coefficients for the vinyl plastic perforated and fibrous cellulose laminated are for flat material 0.013-inch thick, which would have an NRC of 0.60. The same material, if corrugated, has higher absorption coefficients and an NRC of 0.70.

I would like to ask under what conditions the last item under luminous ceilings in Table I was tested, and what the sub-ceiling treatment was. The reason for this question is the extremely high absorption coefficient at 125 cps.

I am sure the author realizes my next point, but many readers of the paper may not. On page 97 in the first paragraph, it is not the presence of low frequency noise alone that affects the ability to hear speech, although the statement that lower frequencies tend to mask higher frequencies is, of course, true. To have speech interference, the intensity of noise must be very large. Actually, one must have 30 to 40 decibels more low frequency energy to appear equally loud with energy in the mid-range. The intensity of the low frequency is what must be guarded against. The material which has more absorption at the low frequencies than at the high frequencies has advantages in this regard.

As in all specialized fields, there are many divergent

*Geiger and Hamme, Ann Arbor, Mich.

*Smithcraft Lighting Division, Chelsea, Mass.
**This error has been corrected for publication in I.E. — EDITOR.

views by the experts, and acoustics is no exception. We can easily find proponents of "loudness criteria" or "reverberation time criteria." Let us not become so clouded with these acoustical issues that we lose sight of the intent of this paper, which is that the acoustical engineer need not oppose the use of luminous ceilings on the basis of NRC alone, which is contrary to popular opinion. In many cases the lower NRC might help the acoustical situation by raising the reverberation time, and in most cases a compromise solution can be made. A better understanding of the acoustical parameters involved will enable us to work more closely and more effectively with the acoustical engineers than we have in the past.

G. W. CLARK:* The comments of the several discussors are greatly appreciated and give encouragement to my personal opinion that the subject of acoustics is a pertinent one for lighting engineers. I find myself in general agreement with all of the discussion, but there are several points I believe worthy of further comment.

Dr. Spencer has added some interesting data, particularly with respect to the acoustical transmittance of vinyl plastic. This adds emphasis to the recommendations of the paper regarding special treatment for sound isolation or insulation where sound can be transmitted through the plastic from one area to another. An attempt to compare directly the data of Dr. Spencer's discussion with that of Table I in the paper will quickly reveal the reason for the word "typical" in the title of the table. The author has seen at least three different published NRC values for corrugated vinyl plastic. Since the plastic in each case was essentially identical, the explanation for the variation probably involves the test procedures.

Mr. Kingsbury's suggestion for acoustical treatment on the walls is significant, particularly for relatively small areas, such as the classrooms he mentions. Of even greater importance, however, is his reminder of the limitations of acoustical absorption in reducing the noise level. These two considerations are illustrated by the data in Table II which indicate that the difference in perceptible noise reduction is essentially equivalent over a wide range of acoustically absorbing material. Incidentally, it should be remembered that the noise reduction (in decibels) listed in Table II is essentially maximum, since the "typical office" used is empty and has practically no absorption on the walls and floors.

I particularly enjoy Mr. Kingsbury's illustration of the problem of sound isolation or insulation, probably because it should be more meaningful to lighting people than more abstract explanation. It has been my personal experience that too many people expect to cope with this problem through the use of acoustically absorbing materials. This is an impractical, if not impossible approach, as Mr. Kingsbury points out.

The author is particularly appreciative of Mr. Hamme's taking the time to prepare a discussion on the paper, and finds his comments especially encouraging. I feel fortunate that his discussion gives authoritative emphasis to the "main-stream" of the paper. As an illuminating engineer, I would have found it difficult to argue with an acoustical consultant of Mr. Hamme's standing.

My thanks to Mr. Lamson for calling my attention to the error in Table I of the paper. This has been corrected for publication, to show the absorption coefficients which correspond to the NRC of 0.70. Since the data shown are to be considered only typical, the detail of corrugation has not been included in the description, though the values are for the corrugated sheet.

In answer to Mr. Lamson's question regarding the condition under which the vinyl plastic luminous ceiling with acoustical sub-ceiling (Table I) was tested, the following description is given from the test report (Geiger & Hamme, 4/6/56):

"¾-inch Fiberglas ceiling board, painted side exposed, spaced 10 inches from rigid backing, covered with plastic diffuser spaced 30 inches from rigid backing."

I have no further explanation for the high absorption at low frequencies except to suggest that it may be, as Mr. Lamson's question inferred, a result of the method of mounting. As he is well aware, the method of mounting acoustical ceilings and the air space between them and the structural ceilings greatly affect their absorption characteristics.

Although a very recent article on noise criteria[1] seems to emphasize the loudness level concept of this paper, I should like to echo Mr. Lamson's suggestion that it is not necessary for the average lighting engineer to become entangled in the details of acoustical calculations and criteria. Table II, for example, represents many hours of calculations which certainly could not be justified as a requirement for being able to sell a lighting installation. It was the author's hope in preparing this paper that it would give the illuminating engineer a sufficiently adequate background in acoustics to be able to use the data and conclusions of the paper as a means of avoiding involvement in the details of their development. It should also enable us to answer comfortably and intelligently most questions regarding acoustics which we get from those for whom we are designing lighting.

1. Kryter, Karl D.: "Noise Control for Buildings," *Noise Control*, Vol. 3, No. 6, pp. 14-20 (November 1957).

*Author.

Applications for Retired Membership

By action of the membership of I.E.S., the new retired membership classifications became effective in the fiscal year beginning October 1956. Privileges in these new grades, earned by long membership in the Society, include reduced annual dues ($5.00) with continued receipt of all Society mailings including ILLUMINATING ENGINEERING. Such members will be designated as Member, Retired; Associate Member, Retired.

Those who are interested and qualified (at least thirty years of membership and 65 years of age) should address a letter to the General Secretary at Society Headquarters, stating that they have retired from regular occupation in business or profession.

INSTALLATION AT HOLLY CARBURETOR PLANT, WARREN, MICHIGAN.

Industrial Lighting

LIGHTING OBJECTIVE: To provide comfortable general illumination for the manufacture of small carburetor parts.

GENERAL INFORMATION: Machining, polishing and grinding automotive and aircraft carburetors is done in the portion shown of the 290-foot by 435-foot manufacturing area. Ceiling height averages 25 feet.

Colors and reflectances of the major room surfaces are:

ceiling	white	80% RF
floor	gray	50% RF
columns		
upper	white	80% RF
lower	light green	60% RF
machines	light green and gray	55% RF

INSTALLATION: Seven hundred individual suspended luminaires, Benjamin Electric Mfg. Co., catalog No. 96122, are installed 10 feet above the floor, in rows 12 feet on centers (the units are spaced two feet apart in each row). Each luminaire is equipped with reflectors permitting a 10 per cent upward component of light, and with two 96-inch T-12 standard cool white fluorescent lamps.

(over)

A.I.A. File No. 31-f

The average maintained level of illumination at the working plane is 80 footcandles. Brightnesses are as follows:

ceiling	56 fL
columns (upper)	105 fL
floor	40 fL
machines	48 fL
luminaires	
crosswise at 30°	900 fL
at 45°	1064 fL
lengthwise at 30°	798 fL
at 45°	893 fL

Lighting designed by Duncan Preston, Detroit Edison Co., Detroit, Mich., and Vern Winn, District Representative, Benjamin Electric Manufacturing Co., Dearborn, Mich.

Lighting data submitted by Vern Winn, Benjamin Electric Manufacturing Co., Dearborn, Mich., as an illustration of good lighting practice and to aid in the design of similar installations.

Published by the Committee on Publications of the Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.

I.E.S. Guide for

Photometric Testing of Outdoor Fluorescent Luminaires

Prepared by the Subcommittee on Photometric Testing of Outdoor Fluorescent Luminaires of the Committee on Testing Procedures for Illumination Characteristics of the Illuminating Engineering Society

FOREWORD

The following guide has been under development since 1952 and has had eight drafts and many minor revisions. Since outdoor fluorescent luminaires are coming into increasing use, there has been a growing need for this testing guide.

SUBCOMMITTEE ON PHOTOMETRIC TESTING OF OUTDOOR FLUORESCENT LUMINAIRES

J. S. Franklin, *Chairman*

J. E. Bock — G. A. Horton — T. H. Leister

COMMITTEE ON TESTING PROCEDURES FOR ILLUMINATION CHARACTERISTICS

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1. Objective

It is the object of this report to provide a guide that will promote uniform test results in determining and reporting the photometric characteristics of outdoor fluorescent luminaires. The characteristics are described in accordance with the following two types of lighting used:

(a) *High Mounting Type* — Data particularly useful for evaluating luminaires used for high mounting purposes such as street and highway lighting luminaires is to be provided. The illumination characteristics are described in terms of the candlepower distribution of the luminaire and a calculated isolux diagram.

(b) *Low Mounting Type* — Data particularly useful for evaluating luminaires used for low mounting purposes, such as luminaires for underpass lighting is to be provided. The illumination characteristics are described in terms of illumination in footcandles measured on a plane surface at a specified distance from and in a specified relationship to the luminaire, and candlepower distribution in both the vertical plane and in the cone containing the maximum candlepower value.

Approved by the Council of the Illuminating Engineering Society, June 1957.

2. Test Conditions — General

2.1—*Luminaires* — Luminaires selected for test should be representative of the manufacturers' typical product. Lamp ballasts regularly furnished as part of the luminaire or recommended for use with the luminaire should be used to operate the test lamp (or lamps) during the test. Ballasts during test should remain within or external to the luminaire, as supplied by the manufacturer, in order that their effect on luminaire photometric performance may be evaluated correctly. The luminaires should be operated under conditions as nearly typical of end-use as possible.

2.2—*Lamps*

2.2.1—*Selection*—A minimum seasoning period of 200 hours is recommended. The test lamp (or lamps) selected for stability should be consistent in light output for constant line voltage and repeated operation. If more than one lamp is required, they should be matched in light output within ±5 per cent when measured on the same circuit. The test lamp (or lamps) should be selected for uniform brightness and color from end to end and around long axis.

2.2.2—*Operating Conditions* — Lamp circuit pin connections should be the same as when the lamps were seasoned and remain the same throughout the test. (For further details refer to the "I.E.S. Guide for the Photometric Measurements of Fluorescent Lamps.")

Lamps and ballasts should be operated until they reach stable operating conditions, particularly as to temperature, because of the variation in light output with a change in temperature. As an added precaution, the test time should be kept to a minimum to avoid changes in the ambient temperature.

2.3—*Electrical Requirements*

2.3.1—*Regulation of Supply*—Where luminaires are intended for multiple supply, the ballast supply voltage should not vary more than ±½ per cent during the test. For series supply, the current should be held within the same limits.

2.3.2—*Wave Form of Supply* — The ballast supply should be such that the rms summation of the harmonic components does not exceed 3 per cent of the fundamental. Where the supply is multiple, the above refers to the ballast supply voltage. For constant-current supply, it refers to the output current of the constant-current transformer (or simulated electrical equivalent).

2.3.3—*Instruments*—The instruments should have good reproducibility of indication and large scale deflection for the conditions under which they are used. They should also be free from frictional and/or heating errors. (See Section 6.1.1 of the "I.E.S. General Guide to Photometry.")

2.3.4—*Operating Conditions*—Ballasts should be operated either at their rated primary voltage or current, and at

their rated frequency. If the ballast used specifies a voltage range, the center of the range should be used.

2.4—*Photometers* — The photometric equipment should be calibrated throughout the entire usable scale so that its individual readings can be reproduced within a tolerance of ±2 per cent. Extraneous or stray light, which might affect the test results, should be eliminated or prevented from reaching either the measuring element or the luminaire. When making candlepower measurements, provisions should be made for correct optical positioning of the luminaire in relation to the photometric axis, and for proper angular setting in both horizontal and vertical directions. When making illumination measurements, an instrument that is substantially cosine-corrected should be used. (See Sections 5.2.1 and 6.2 of the "I.E.S. General Guide to Photometry.")

3. Test Procedure (High Mounting Type)

3.1—*Test Distance* — The test distance should be sufficient to give representative candlepower measurements. This usually requires at least five times the maximum luminaire dimension. The photometric test distance is defined as the distance from the center of the lamps to the surface of the test plate or photosensitive element. With luminaires in which the lamps do not all lie in the same plane, the test distance should be measured to the geometric light center position. (See Section 4.1 of the "I.E.S. General Guide to Photometry.")

3.2—*Photometer Calibration*

3.2.1—*General* — Calibration is necessary to relate the light output of the test lamps to the lamp manufacturer's initial rated lumen output at 25C. Two methods are described below.

3.2.2—*Relative Method (High Mounting Type)* — The relative candlepower readings of the test lamp (or lamps) alone and of the lamp-luminaire combination are made with the ballast input held constant in both tests. The calibration may be made by taking a photometer reading normal (90 degrees) to the test lamps operated outside the luminaire, and assigning to the arbitrary units of that reading the calculated value that would result if the lamps being measured were delivering rated lumen output. All subsequent readings of luminaire candlepower are then directly proportional to this reading. (For further details refer to the "I.E.S. Guide for Electrical Measurements of Fluorescent Lamps" and the "I.E.S. Guide for Photometric Measurements of Fluorescent Lamps.")

3.2.2.1—*Test Lamps* — When photometering the test lamps to establish the calibration, the following conditions should be observed:

(1) Lamps should be mounted in open air outside the luminaire, preferably in a horizontal position, and their position should be parallel to the test plate or light-sensitive surface. Reflecting surfaces and drafts should be eliminated.

(2) Electrical conditions, instruments and test distance should be the same as for the luminaire test.

(3) Lamps should be operated on the same circuits of the same ballasts used in the luminaire tests. All lamps should be operating during period of calibration.

(4) Lamps and ballasts should reach stable operating conditions before readings are taken.

(5) The ambient temperature at time of calibration should be 25C ± 1C. If it is not, it is then necessary to establish relative light output in per cent vs. ambient temperature for the particular type of lamps being tested and over a range of ambient temperature which may exist during the calibration.

3.2.2.2—*Photometer* — **(a)** Determine lumen/normal candlepower ratio, which is the ratio of bare lamp lumens to the normal (90 degrees) candlepower of all lamps used. (It should be noted that this ratio is consistent regardless of the photometer measuring circuit setting. An arbitrary lumen value may be calculated by means of zonal constants and the ratio established. This is the key to the relative method.) When using more than one lamp, lamps may be photometered singly averaging their readings, or in a group. If measured in a group they should be mounted so as to prevent interreflections between lamps and mutual heating effects.

(b) The deflection, or reading in arbitrary units, taken normal (90 degrees to the lamp (or lamps)) under these conditions should be assigned a value equal to the normal candlepower that would result if the lamps were delivering rated lumens. The formula is:

$$CP = \frac{n \times L_R \times M}{D}$$

where:

CP = Candlepower at test ambient temperature

n = Total number of lamps

L_R = Rated lumen output per lamp at 25C

M = Correction factor established from test which corrects lamp lumens at 25C to particular ambient temperature at time of calibration. For an ambient temperature of 25C ± 1C, $M = 1$.

D = Average lumen/normal measured ratio. This is simply a means of averaging variations in individual lamp candlepower by averaging the lumen/normal measured ratios of the "n" individual lamps.

Having thus established corrected bare lamp candlepower at the test ambient temperature, the photometer is calibrated in terms of candlepower.

3.2.3—*Direct Method (High Mounting Type)* — In the direct method both the test lamp (or lamps) and photometer should be calibrated against standards.* (For further details refer to the "I.E.S. Guide for Electrical Measurements of Fluorescent Lamps," and the "I.E.S. Guide for Photometric Measurements of Fluorescent Lamps.")

3.2.3.1—*Test Lamps*—The lumen output of the test lamp (or lamps) should be determined at an ambient temperature of (or corrected to) 25C ± 1C in an integrating sphere or by an equivalent method while under the same electrical operating conditions as those used in testing the luminaire.

3.2.3.2—*Photometer* — **(a)** The photometer, whether of the physical or visual type, should be calibrated by means of a candlepower standard.*

(b) To calibrate the photometer in candlepower in terms of the rated lumen output of the lamps at 25C, proceed as follows: With a known intensity of light (candlepower standard)

*A lumen or candlepower standard is a light source which has been calibrated by a recognized standardizing laboratory as to lumen output and/or candlepower in a given direction.

presented to the surface of the test plate or photosensitive element at the test distance to be used, the measuring circuit should be adjusted to read the value CP as given in the following formula:

$$CP = CP_{std} \times \frac{n \times F_R}{F_{T_1} + F_{T_2} + \ldots + F_{T_n}}$$

where:

CP = Candlepower (prorated)

CP_{std} = Candlepower of standard lamp*

F_R = Rated lumen output at 25 C for the type of fluorescent lamp employed

F_T = Actual lumen output at 25 C of the fluorescent test lamp (or lamps)

n = Total number of lamps

The photometer will then be calibrated to give readings in candlepower as though the lamp (or lamps) were putting out rated lumens at 25 C.

(c) If the circuit cannot be adjusted all readings may be multiplied by the ratio of CP divided by measuring circuit reading with a known intensity of light (candlepower standard) presented to the surface of the test plate or photosensitive element at the test distance to be used.

3.3—*Luminaire Candlepower Measurements*—(See Section 6.6 of the "I.E.S. General Guide to Photometry.")

3.3.1—*Mounting* — The luminaire should be mounted for test on a suitable frame and in a manner which will allow prescribed candlepower measurement to be made for the type of luminaire tested.

3.3.2—*Readings* — **(a)** Photometric readings should be taken with the luminaire in its normal end-use position or provisions made to correct readings taken in any other position. Departure from normal operating position affects the photometric readings, because of temperature variations within the luminaire. When the readings are taken, it is necessary to measure the bulb wall temperature with the luminaire in normal operating position.

(b) The ambient temperature at times of luminaire test should be 25 C ±1 C. If this is not possible a temperature correction may be made. For this correction and other temperature data see Appendix D.

3.3.3—*Angles for Measurement*

3.3.3.1—*Points* — The number of points measured photometrically in various vertical planes and the angular spacing between points should be such as to permit plotting of well-determined (interpolation held to a minimum) candlepower distribution curves. Steps of 10-degree intervals in a vertical plane are usually satisfactory. Shorter intervals are recommended when the distribution curve is changing rapidly or is irregular in form.

3.3.3.2—*Planes* — The number of vertical planes explored should be determined by the nature of the candlepower distribution as to symmetry or irregularity. Planes at 15-degree intervals are recommended, *i.e.*, 7½, 22½, 37½ degrees, etc., with readings at similar vertical angles in the 0-degree and 180-degree planes. The orientation of the 0 degree plane relative to the lamp axis should be clearly recorded. In the case of decidedly symmetrical distribution, three planes may be sufficient, *i.e.*, at 0, 45, and 90 degrees. For five planes, add those at 22½ and 67½ degrees.

3.4—*Computation*

3.4.1—*General*—The process of developing useful results involves the following steps:

3.4.2—*Computing Candlepower* — **(a)** The photometric readings should be converted into candlepower based upon lamp delivering rated lumens at 25 C in still air by applying the factor determined from the calibration of the photometer and test lamps. These values establish the candlepower distribution at the test room ambient temperature; and subsequent calculations of zonal lumens, luminaire output, etc. are then, or can be, made available for a 25 C reference ambient.

(b) To change this candlepower data to correspond to a 25 C ambient temperature, one of the following methods may be used.

(1) If test room ambient temperature is 25 C during both calibration and luminaire test, then candlepower values as recorded are correct for 25 C reference ambient temperature.

(2) If test room ambient temperature is *other* than 25 C during both calibration and luminaire test, then candlepower values as recorded should be corrected to a 25 C ambient temperature. This method uses the average light output as determined by two independent temperature measurements: (1) test room ambient temperature, (2) average of test lamp (or lamps) bulb wall temperature. For details on the computation of correction factor, refer to Appendix D.

(c) If a curve of bulb wall temperature vs. ambient temperature (Appendix D) is available at the time of test, and the ambient temperature during calibration and testing is the same, final candlepower values can be obtained directly in terms of the 25 C reference ambient temperature by the procedure under photometric calibration 3.2.2.2 (b):

$$CP = \frac{(n \times L_R \times M)\, C}{D}$$

Where C = correction factor (from (b) (2) above). Corrects lamp lumens at the test ambient to the 25 C reference ambient temperature.

3.4.3—*Computing Zonal Lumens* — By multiplying the candlepower values found in each of the planes of measurement by the appropriate constants from Appendix A, the lumens for the corresponding segment of each zone are obtained. The addition of all such lumen values corresponding to a given vertical angle of measurement will supply the lumens in the total zone represented. If planes are measured in only one quadrant, particular care must be used in the evaluation of lumens by summation, in order to avoid giving double weight to segments of zones which overlap from one quadrant to another.

3.4.4—*Isolux*—**(a)** Calculate the horizontal footcandle values for the vertical angles listed in Appendix E for each lateral angle through which a vertical candlepower distribution curve has been taken. (Section 3.3.3.2)

(b) Plot horizontal footcandles *vs* the tangent of the vertical angle. This may be done on semi-log paper or on rectangular coordinate paper if the ordinate (horizontal footcandle) scale is changed each time the horizontal footcandle value goes below one tenth

*A lumen or candlepower standard is a light source which has been calibrated by a recognized standardizing laboratory as to lumen output and/or candlepower in a given direction.

the full scale value.

(c) The Isolux Chart has as its scale a ratio of distance to mounting height which is the tangent of the vertical angle. Radial lines may be drawn on the chart representing the intersection of the vertical planes through which candlepower values were recorded. Then from the horizontal footcandles *vs* tangent curves, desired horizontal footcandle values may be selected, plotted, and values of equal illumination joined by a smooth curve to form the Isolux Chart.

3.4.5—*Luminaire Efficiency*—Per cent efficiency (total luminaire lumens divided by bare lamp lumens) for outdoor fluorescent luminaires is not a fixed value because light output changes with a variable ambient temperature present in this kind of application. It is also important to note that significant changes in light output can be caused by movement of air. It is therefore recommended that light output or utilization be expressed in lumens at the ambient temperature of 25C and in still air, and that a table of correction factors be supplied for ambient temperature ranging from approximately 90F to 0F. (Fahrenheit scale used for application purposes.) (Factor 1 at 77F (25C) Ambient.)

3.4.6—*Calculation of Lumen Utilization*—On the isolux chart lay off squares whose sides are ½ by ½ or smaller in the area of the luminaire. At the center of these squares read the horizontal footcandle value. The lumens in any square may then be calculated from the fundamental equation:

Lumens = Average footcandles × area,

where average footcandles is the horizontal footcandle value at the center of the area and the area is the square of ½ mounting height.

The lumens in the squares may then be summed in successive strips parallel to the curb line and a plot of utilized lumens *vs* transverse distance divided by mounting height may be made. It should be noted that if isolux is shown for only one side of axis of symmetry utilized lumen strips will double.

4. Test Procedure (Low Mounting Type)

4.1—***Test Distance***—The test distance will vary during the test, depending on the location of the test station within the area of the test surface.

4.2—***Photometer Calibration***—**(a)** As in the high mounting type procedure, the photometer (portable type) may be calibrated with the test lamp or lamps without regard to their actual lumen output.

(b) The method of calibration is the same as outlined in 3.2 except that test distance during calibration is not related to the luminaire test distance and the assigned 90-degree candlepower should be converted to footcandles.

(c) The assigned normal (90-degree) candlepower (3.2.2.2 (b)) may be converted to footcandles by dividing by the test distance squared. All subsequent footcandle readings should be related to the calculated value.

4.3—***Measurements***

4.3.1—*Luminaire Illumination Measurements*—The electrical conditions should remain the same as in the calibration procedure. The luminaire should be suspended in a suitable position with respect to the plane of illumination measurements. If this position is in other than normal operating position, compensation should be made for change in luminaire output due to temperature differences (see Section 3.3.2). The area of the surface lighted by the luminaire should be divided into a suitable number of rectangular areas. Dimensions and layout of these areas should be such that significant differences in illumination will be indicated within the entire area which the luminaire is intended to illuminate. Illumination measurements should be made at the center of each area.

4.3.2—*Luminaire Candlepower Measurements*—See Section 3.3, except that measurements need be made only in the vertical plane and cone of maximum candlepower.

4.4—***Computation***—All illumination measurements should be corrected by applying the factors determined through the calibration of the photometer and the test lamp or lamps.

5. Test Report

5.1—***General***—**(a)** The test report should describe all significant data found concerning the luminaire tested and the data should be listed in a manner that will allow derivation of the maximum amount of information.

(b) It is recommended that the items listed below and illustrated in Appendix D be included and that report forms of the general type shown in Appendix B be used. Candlepower, lumen and footcandle values illustrate format rather than actual test values.

5.2—***Luminaire Description***

(a) Manufacturer's name, type and catalog number.
(b) Reflector—shape, material, manufacturer's designation and dimensions.
(c) Type and size of glassware or other enclosure and method of attachment.
(d) Auxiliary reflecting devices.
(e) Other essential information, including method of selection of sample.
(f) Type and location of ballast whether inside or outside luminaire.

5.3—***Test Lamp Description***

(a) Number, type and bulb designations.
(b) Rated watts.
(c) Rated lumen output at 25C.

5.4—***Results—(High Mounting Type)***

(a) Candlepower distribution curves in the vertical plane and in the cone containing the maximum candlepower value.
(b) Isocandle curve plot for asymmetric types. (Optional.)
(c) Utilization street and house side with luminaires parallel, at right angle to curb, and/or with angle of tilt.
(d) Temperature correction table or curve. (See Appendix D.)
(e) Test distance.
(f) Lumen output of luminaire and total lumens in each of the four quadrants. (Upward street side, upward house side, downward street side and downward house side.)
(g) Horizontal footcandle lines of equal illumination, isolux, computed for a suggested 30-foot mounting height and table of correction factors for other heights 20 to 35 feet).
(h) Date and testing agency.

5.5—***Results—(Low Mounting Type)***

(a) Candlepower distribution curves in the vertical plane and in the

cone containing the maximum candlepower value.

(b) Horizontal footcandle lines of equal illumination, isolux, for mounting height recommended by manufacturer.

(c) Temperature correction table or curve. (See Appendix D.)

(d) Perpendicular distance to test surface and angular orientation of luminaire.

(e) Date and testing agency.

APPENDIX A — CONSTANTS FOR THE CONVERSION OF CANDLEPOWER INTO LUMENS
(For readings at 10° intervals in vertical planes)

	Vertical Angles	K
Planes at 15° Horizontal intervals, at 7½°, 22½°, 37½°, etc. (Note that the constants are equal to 1/24 of the conventional zonal lumen constants.)	5 or 175	0.0040
	15 or 165	0.0118
	25 or 155	0.0193
	35 or 145	0.0262
	45 or 135	0.0322
	55 or 125	0.0374
	65 or 115	0.0414
	75 or 105	0.0441
	85 or 95	0.0455
Planes at 45° Horizontal intervals, at 0°, 45°, 90°. (Note that the constants are equal to ⅛ of the conventional zonal lumen constants.)	5 or 175	0.0120
	15 or 165	0.0354
	25 or 155	0.0579
	35 or 145	0.0786
	45 or 135	0.0966
	55 or 125	0.1122
	65 or 115	0.1242
	75 or 105	0.1323
	85 or 95	0.1365
Planes at 22½° Horizontal intervals, at 0°, 22½°, 45°, 67½°, 90°. (Note that the constants are equal to 1/16 of the conventional zonal lumen constants.)	5 or 175	0.0060
	15 or 165	0.0177
	25 or 155	0.0289
	35 or 145	0.0393
	45 or 135	0.0483
	55 or 125	0.0561
	65 or 115	0.0621
	75 or 105	0.0662
	85 or 95	0.0683

NOTE: If it is desired to determine the lumens emerging on, say, the street side for a street lighting luminaire, care must be exercised in the addition of lumens resulting from measurements in the 90° and 270° planes, since the zonal segments overlap the curb line.

For Appendix B, see the following page.

APPENDIX C — THERMOCOUPLE ATTACHMENT METHOD

1. *General* — The following method of installing thermocouples for fluorescent lamp bulb wall temperature measurements has been successfully used for many years and has consistently given accurate, reproducible results.

Since the technique of measuring temperature by means of thermocouples is well understood, only the method of attaching the thermocouples to a fluorescent lamp will be described.

The method described minimizes radiation effects from the lamp affecting the true bulb wall temperature.

2. *Thermocouple Installation Method* (See Fig. 1) — The thermocouple is located approximately one foot in from the end of the lamp and on the underside of a horizontally operated lamp. The temperature at this point is more nearly representative of operating conditions within the lamp.

A #30 AWG thermocouple should be used. The thermocouple wires should not be twisted at the bead, but brought away immediately in the form of a "V." The side of the junction toward the bulb wall should be flattened and scraped or polished. The bow or bump (approximately ⅛ inch high) is placed in the couple wires immediately back of the junction point. This bow is to produce sufficient tension to hold the junction point firmly against the glass bulb. The thermocouple is held in place by the use of asbestos cord. One cord is placed directly back of the bow in the couple, and two or three more cords are usually placed along the couple so as to hold the couple firmly and prevent its twisting. No cord or other substance is placed over the junction point of the couple as this would affect the absorption and give an error in a reading. In addition, the couple for at least one inch back of the bow must be in good contact with the bulb or else the couple wires will conduct heat away from the junction point and will produce a low reading. For this reason, it is important that the couple follow along the underside of the lamp since that will be close to the same temperature as that of the point being measured. The junction will absorb some light and heat and thus tend to give a high reading. These two conditions offset or partially offset each other. The thermocouple wire should be firmly secured on the lamp base by means of glass tape. Keeping both the junction and the bow small makes the possible error also small.

APPENDIX D — TEMPERATURE CORRECTION FACTORS

In order to obtain the following temperature correction curves, it is necessary to have a temperature controlled enclosure large enough to house the luminaire. It is also necessary to have minimum movement of air about the luminaire during the stabilization and reading of the light output at a given luminaire ambient temperature; however, this does not mean that there is anything undesirable about the normal convection currents due to the luminaire's own heat.

Even if a large "walk-in" type temperature controlled room is used, it would be advisable to have the instrumentation

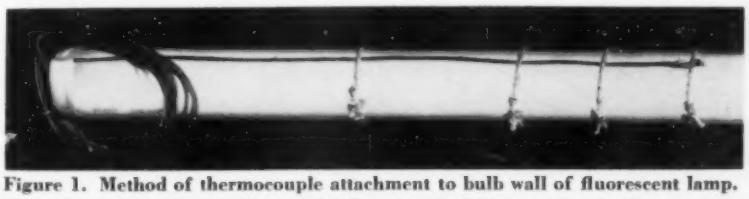
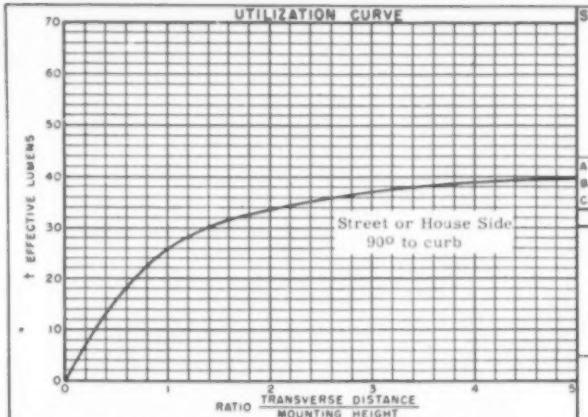


Figure 1. Method of thermocouple attachment to bulb wall of fluorescent lamp. View showing thermocouple bead held against bulb by means of asbestos cord, and firmly secured at end of lamp by glass tape.

APPENDIX B — GENERAL TYPE OF REPORT FORM. CANDLEPOWER, LUMEN AND FOOTCANDLE VALUES ILLUSTRATE FORMAT RATHER THAN ACTUAL TEST VALUES.

UTILIZATION CURVE



† NOTE: FLUORESCENT LUMINAIRES – ON ROAD SURFACE IN HUNDREDS
ALL OTHER LUMINAIRES – IN PERCENT OF BARE LAMP LUMENS

CALCULATIONS

LUMENS / SQ FT (AVG FT-C) ON STREET = EFFECTIVE LUMENS* / SPACING X WIDTH OF STREET

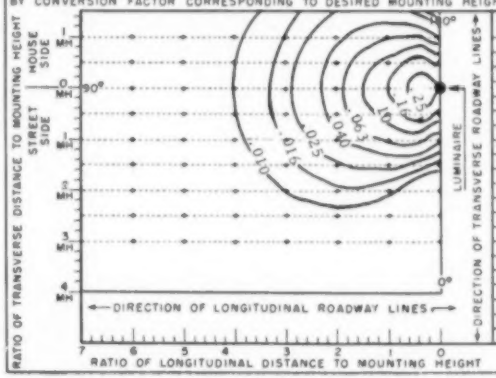
CALCULATIONS BASED ON UNITS ON ONE SIDE OF STREET OR STAGGERED POSITION (WITH OPPOSITE ARRANGEMENT VALUES SHOULD BE DOUBLED) SPACING DENOTES DISTANCE ON CENTER LINE OF STREET BETWEEN ADJACENT UNITS

*NOTE: TO OBTAIN MAINTAINED ILLUMINATION VALUES RECOMMENDED BY IES MULTIPLY EFFECTIVE LUMENS BY THE LAMP AND LUMINAIRE MAINTENANCE FACTORS

ISOLUX DIAGRAM

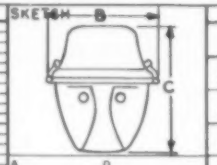
ILLUMINATION IN HORIZONTAL FOOT CANDLES
CALCULATED FOR A MOUNTING HEIGHT OF 20 FEET **
ILLUMINATION DIRECTLY UNDERNEATH LUMINAIRE 0.22 FT-C

** NOTE: TO OBTAIN ILLUMINATION FOR OTHER MOUNTING HEIGHTS, MULTIPLY VALUES OF ILLUMINATION BY CONVERSION FACTOR CORRESPONDING TO DESIRED MOUNTING HEIGHT USE COLUMN] IN TABLE


RATIO OF TRANSVERSE DISTANCE TO MOUNTING HEIGHT
HOUSE SIDE
STREET SIDE
LUMINAIRE
DIRECTION OF TRANSVERSE ROADWAY LINES
DIRECTION OF LONGITUDINAL ROADWAY LINES
RATIO OF LONGITUDINAL DISTANCE TO MOUNTING HEIGHT

MOUNTING HEIGHT	CONVERSION FACTOR 1	2	3
15	1.78		
16	1.56		
17	1.39		
18	1.23	1.93	2.78
19	1.11	1.73	2.49
20	1	1.56	2.25
21	0.91	1.42	2.04
22	0.83	1.29	1.86
23	0.76	1.18	1.70
24	0.69	1.09	1.56
25	0.64	1	1.44
26	0.59	0.93	1.33
27	0.55	0.86	1.24
28		0.80	1.15
29		0.74	1.07
30		0.69	1
31		0.65	0.94
32		0.61	0.88
33			0.83
34			0.78
35			0.74

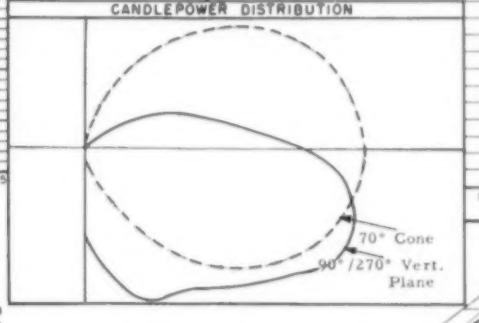
SKETCH



LIGHT FLUX VALUES

	LUMENS	PERCENT OF LAMP
DOWNWARD STREET SIDE	430	
UPWARD STREET SIDE	85	
DOWNWARD HOUSE SIDE	430	
UPWARD HOUSE SIDE	85	
TOTAL	1030	

CANDLEPOWER DISTRIBUTION



ANGLE	CANDLEPOWER CONE	VERT PL
180	8	
175	9	
165	26	
155	60	
145	110	
135	155	
125	206	14
115	242	64
105	262	112
95	270	167
90	272	209
85	270	243
75	262	272
65	242	269
55	206	226
45	155	194
35	110	171
25	60	167
15	26	138
5	9	107
0	8	88
MAX	273	273

RELATED CURVES

LUMINAIRE (DESCRIPTIVE MATERIAL)

CANDLEPOWER, LUMEN, AND FOOTCANDLE VALUES SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY

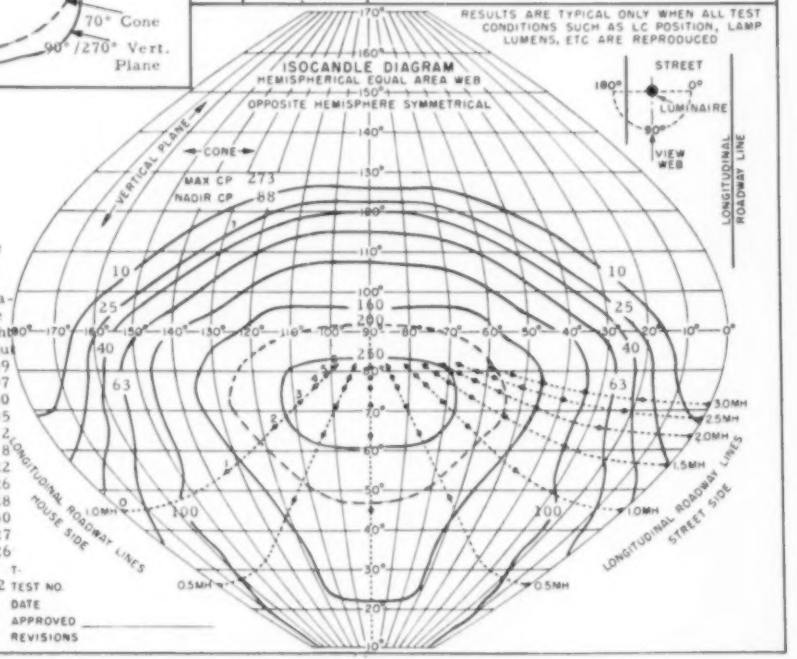
LAMP - TYPE F24T12/CW/RS
VOLTS AMPERES WATTS
BASE Medium Bipin BULB T12 LC LENGTH IN
FILA HEIGHT MM WIDTH MM
LIGHT OUTPUT (TEST CONDITIONS) (2) 2600 LUMENS
OPERATING POSITION Horizontal

PHOTOMETER - TYPE Polar Axis Vertical
TEST DISTANCE 25 FT AMBIENT TEMP 77 F

RESULTS ARE TYPICAL ONLY WHEN ALL TEST CONDITIONS SUCH AS LC POSITION, LAMP LUMENS, ETC ARE REPRODUCED

ISOCANDLE DIAGRAM

HEMISPHERICAL EQUAL AREA WEB
OPPOSITE HEMISPHERE SYMMETRICAL



Temperature Correction Factors

Ambient Temp. F	Relative Light Output
90	0.89
80	0.97
77	1.00
70	1.05
60	1.12
50	1.18
40	1.22
30	1.26
20	1.28
10	1.30
0	1.27
-10	1.26

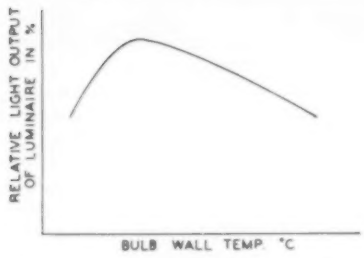
Moving Air Approx. 0-2 MPH

TEST NO.
DATE
APPROVED
REVISIONS

outside of the room in order to avoid errors in readings due to temperature.

If these conditions can be satisfactorily established, proceed to measure relative light output of luminaire in per cent *vs* bulb wall temperature (see Appendix C for details) of the lamp (or lamps) in the luminaire, over a range of approximately 30C to −30C ambient temperature about the luminaire. From this data, plot curves of relative light output in per cent *vs* bulb wall temperature and bulb wall temperature *vs* ambient temperature of luminaire.

Curve: Light Output *vs* Bulb Wall for Lamps in Luminaire



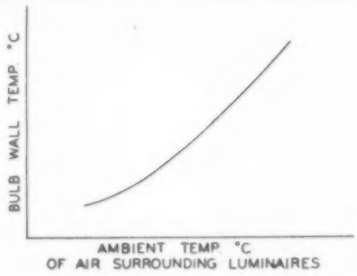
Given: Average bulb wall temperature with luminaire in normal operating position

Find: Light output

Solution: On curve above, read light output for given bulb wall temperature. Call value "*a*."

Compute Correction Factor $\frac{\text{"}a\text{"}}{100} = \frac{\text{"}d\text{"}}{Y}$

Curve: Bulb Wall *vs* Ambient for Lamps in Luminaire



Given: Ambient temperature at time of test

Find: Light output

Solution: On curve above, read bulb wall for given ambient. On previous curve read corresponding light output for bulb wall found. Call value "*b*."

Given: 25C reference ambient temp.

Find: Light output

Solution: On curve above read bulb wall for 25C ambient. On previous curve read corresponding light output for bulb wall found. Call value "*d*."

Compute Correction Factor $\frac{\text{"}b\text{"}}{100} = \frac{\text{"}d\text{"}}{X}$

Correction Factor $C = \frac{X+Y}{2}$

Appendix E — Horizontal Footcandles = Candlepower Times Cosine Cubed of Vertical Angle Divided by the Mounting Height Squared

Table of Constants for $\frac{\text{Cos}^3 \text{ Vertical Angle}}{(\text{Mounting Height})^2}$

Vertical Angle	Mounting Height 20 Feet	25 Feet	30 Feet	Tangent
0	.002500	.001600	.001111	.0
5	.002477	.001583	.001099	.087
10	.002390	.001530	.001061	.176
15	.002270	.001442	.001001	.268
20	.002080	.001330	.0009225	.364
25	.001861	.001190	.000826	.466
30	.001626	.001041	.000722	.577
35	.001377	.000880	.000611	.700
40	.001125	.000720	.000500	.839
45	.000885	.000560	.000393	1.000
50	.000665	.000426	.0002956	1.191
55	.000473	.0003025	.0002100	1.428
60	.0003125	.0002000	.0001389	1.732
65	.0001890	.0001209	.0000839	2.144
70	.0001002	.0000641	.0000445	2.747
75	.0000433	.0000277	.00001922	3.732
78	.0000225	.00001441	.00001000	4.704
80	.00001303	.00000833	.00000578	5.671
81	.00000950	.00000608	.00000422	6.313
82½	.00000558	.00000357	.00000248	7.596
83	.00000450	.00000288	.00000200	8.144
84	.00000275	.00000176	.00000122	9.514
85	.00000175	.00000112	.00000078	11.430
86	.00000075	.00000048	.00000033	14.300

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2. Little, W. F.; Salter, E. H.: "The Measurement of Fluorescent Lamps and Luminaires," Illuminating Engineering, Vol. XLII, p. 217 (February 1947).

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4. Horton, G. A.: "Modern Photometry of Fluorescent Luminaires," Illuminating Engineering, Vol. XLV, p. 458 (September 1950).

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16. Illuminating Engineering Nomenclature and Photometric Standards, 1942 (ASA Z7.1-1942); Illuminating Engineering Nomenclature and Photometric Standards, 1958, Illuminating Engineering, Vol. LII, p. 600 (November 1957).

17. I.E.S. Guide for Photometric Testing of Street Lighting Luminaires, 1948, included in the I.E.S. Guides to Testing Procedures, 1950, Illuminating Engineering Society, New York, N. Y.

Address Changes should be reported to I.E.S. Headquarters by the first of any month, to insure the uninterrupted mailing of I.E. and other Society communications.

Here and There with I.E.S. Members

I.E.S. President Kirk M. Reid was honored guest speaker at the December 9 meeting of the Connecticut Section. Left to right, in photo, are: Walter L. Ball, Chairman, New England Section; President Reid; John K. French, Chairman, Yankee Chapter; Robert D. Babcock, Chairman, Connecticut Section. Members of the New England and Yankee groups were also present. Photo courtesy *New England Electrical News.*

Presentation of the award won by Alan Gallion (right) in the national competition of the Allied Arts Committee in Atlanta, last September, was made at the December 4 meeting of the Southern California Section. Presenter of the award is Dean Arthur Gallion of the School of Architecture, University of Southern California — his father. Attendance at the meeting was 140.

Publications Committee of I.E.S. in session. Left to right: C. E. Ellis, I.E. Advertising Manager; Eve Freyer; Dr. R. M. Zabel, Chairman of the Committee; R. W. Morris; and J. R. Chambers.

Residential Lighting Fixture Progress Report, 1957, was the theme of the October meeting of the Twin City Residence Lighting Forum, at Northland Electric Supply Co. Left to right are: Donald Olson, program chairman; Mrs. Marianne Battig, vice-chairman; Richard Graf, chairman; Richard White, membership chairman; Anita Benson, past-chairman; and Donald Carlson, secretary-treasurer.

LIGHTING NEWS

Light and Vision Conference To Be Held at U. of Michigan

A three-day conference on light and vision will be held at the University of Michigan campus, March 19-21. Public health officials, industrial hygienists, school administrators, architects and engineers will then discuss the new proposed lighting recommendations which will have been announced at the March 3-4 symposium of the Illuminating Engineering Research Institute, Dearborn, Mich. (See January IE, page 7A.) These new proposed recommendations will be based on the researches of Dr. H. Richard Blackwell of the University of Michigan's Vision Research Laboratory.

The conference is one of a series sponsored by the Michigan School of Public Health, and will feature the following topics and speakers:

March 19 — Light and Vision

MORNING SESSION — *Presiding*, Seward E. Miller, Director, Institute of Industrial Health, University of Michigan.
Introduction — Henry F. Vaughan, Dean, School of Public Health, University of Michigan.
Ophthalmological Aspects — Franklin M. Foote, Executive Director, National Society for Prevention of Blindness, New York, N. Y.
Illuminating Engineering Aspects — E. M. Strong, Cornell University, Ithaca, N. Y.
Light and Its Measurement — B. S. Pritchard, Engineering Research Institute, University of Michigan.
AFTERNOON SESSION — *Presiding*, Glenn A. Fry, Director, School of Optometry, Ohio State University, Columbus, Ohio.
Light and Visual Performance — H. Richard Blackwell, Director, Vision Research Laboratories, University of Michigan.
Light and Ocular Physiology—Mathew Alpern, Assistant Professor of Ophthalmology, University of Michigan.
Light and Comfort — S. K. Guth, Manager, Radiant Energy Effects Laboratory, General Electric Co., Cleveland, Ohio.

March 20 — Principles Applied in Solution of Lighting Problems

MORNING SESSION — *Presiding*, Charles D. Gibson, California State Department of Education, Los Angeles, Calif.
Coordination of Daylight and Electric Light — C. L. Crouch, Technical Director, I.E.S., New York, N. Y.
Daylighting — R. A. Boyd, Engineering Research Institute, University of Michigan.
Impact of Lighting on Architectural Design — R. B. Lytle, Jr., Assistant Professor of Architecture, University of Michigan.
AFTERNOON SESSION — *Presiding*, Warren A. Cook, School of Public Health and Institute of Industrial Health, University of Michigan.
Electric Lighting Sources, Control and Fundamentals of Design — M. N. Waterman, Assistant Commercial Engineering Manager, Lamp Division, Westinghouse Electric Corp., Bloomfield, N. J.
Light and Color — R. C. Allison, Engineering and Design Dept., T. Eaton & Co., Ltd., Toronto, Ont.
Maintenance — C. M. Holden, Manager, Commercial Engineering, Champion Lamp Works, Lynn, Mass.
Lighting Survey — G. D. Clayton, Air Pollution and Industrial Health Consultant, Detroit, Mich.
EVENING SESSION — *Presiding*, P. N. Youtz, College of Architecture and Design, University of Michigan.
New Knowledge on Lighting Through Research — K. M. Reid, Senior Illuminating Engineer, General Electric Co., Cleveland, Ohio.

March 21 — Section I, School Lighting

MORNING SESSION — *Presiding*, Russell E. Wilson, Associate Professor of Education, University of Michigan.
School Lighting from an Architect's Viewpoint — Henry L. Wright, Kistner, Wright & Wright, Los Angeles, Calif.
School Lighting from an Educator's Viewpoint — Charles D. Gibson, California State Department of Education, Los Angeles, Calif.
School Lighting from an Engineer's Viewpoint — John M. Chorlton, Board of Education, Toronto, Ont.
AFTERNOON SESSION — *Presiding*, Wilfred E. Clapp, Michigan Dept. of Public Instruction, Lansing, Mich.
Field Clinic — An Objective Study of Visual Problems on the Site, in Selected Schools in the Community.

March 21 — Section II, Office and Industrial Lighting

MORNING SESSION — *Presiding*, J. C. Radcliffe, Supervisor, Industrial Hygiene Unit, Medical Section, Ford Motor Co., Dearborn, Mich.
Applications of the Four Factors of Seeing to a Variety of Industrial Applications (slides) — Floyd Sell, Supervisor, Commercial Sales, The Detroit Edison Co., Detroit, Mich.
Proper Lighting of Hazardous Areas (Combined with Outdoor Lighting) — Richard W. Scott, Manager, Great Lakes Division, Crouse-Hinds Co., Detroit, Mich.
Maintaining Lighting Levels in the Plant — E. A. Linsday, Industrial Lighting Section, General Electric Co., Cleveland, Ohio.
Visual Comfort in the Plant — W. H. Kahler, Lighting Division, Westinghouse Electric Corp., Cleveland, Ohio.
AFTERNOON SESSION — *Presiding*, Earl R. Domoney, Saginaw Division, Consumers Power Co., Saginaw, Mich.
Visual Comfort in the Office — John J. Neidhart, Illuminating Division, The Miller Co., Meriden, Conn.
Maintaining Lighting Levels in the Office — W. A. Stannard, General Lighting Sales Supervisor, Consumers Power Co., Jackson, Mich.
Lighting in Corridors, Conference Rooms, Cafeterias, Lobbies, Rest Rooms — James F. Finn, The Detroit Edison Co., Detroit, Mich.
Lighting Layout Design — George W. Clark, Manager, Engineering, Sylvania Electric Products Inc., Wheeling, W. Va.

1958 Regional Conferences, I.E.S.

Region	Place	Date
Northeastern	Statler Hotel Hartford, Conn.	April 10-11
East Central	John Marshall Hotel Richmond, Va.	April 14-15
South Central and Southeastern	Lafayette Hotel Little Rock, Arkansas	April 24-25
Southwestern	Washington Youree Shreveport, La.	April 28-29
Midwestern	Hotel President Kansas City, Mo.	May 1-2
Inter-Mountain	Whitman Hotel Pueblo, Colo.	May 8-9
South Pacific Coast	El Cortez Hotel San Diego, Calif.	May 12-13
Pacific Northwest	Multnomah Hotel Portland, Oregon	May 22-24
Great Lakes	Sheraton Hotel Rochester, N. Y.	June 23-24

Conference on Engineering and Scientific Education — Understanding Science

A scarcity of people who understand science; what it means and how it affects their lives may well be America's greatest national technological shortage. In fact, this lack of a scientific consciousness by the country's millions of non-scientists could be a most serious detriment in the battle between the laboratories of the world.

This was one of several basic conclusions reached by some 30 of America's top scientists at the Conference on Engineering and Scientific Education — Foundation of National Strength sponsored jointly by the Engineering Manpower Commission of the Engineers Joint Council, National Academy of Sciences — National Research Council, National Science Foundation and the Scientific Manpower Commission.

Sponsored locally in Chicago by the Western Society of Engineers, the high-level probing study into America's technological present and future continued from October 31 to November 2 at the Edgewater Beach Hotel, Chicago. Representing IES at the meeting was Joseph A. Schneller, Midwest Regional Vice-President.

Calling for a much greater scientific educational base throughout American education, Dr. M. H. Trytten pointed out that "a much heavier emphasis on scientific subjects at all levels in our educational system would be helpful even though the students in such cases do not intend to specialize in technical fields."

Dr. Trytten, director, office of scientific personnel, National Academy of Sciences, National Research Council continued, "The rapid increase in technical control of the functions of personnel in many fields should mean that they would be more effective had they had more familiarity with the scientific and technical backgrounds of their activities. This applies today in a wide area of activities, including politics, business, and human relations," he concluded.

Conference key-noter, Dr. Lee A. DuBridge, president, California Institute of Technology, called attention to the fact that "One brilliant creative scientist or engineer may turn up with more than 100 ordinary ones. He may, in fact, need the help of the 100 in putting his ideas to use. Hence, while we are educating the 100 we should not fail to find and encourage and give special attention to the *one*. Since we cannot always pick out 'the one' at an early age, we must provide opportunities for *many* — and we will need the many, too."

Dr. DuBridge continued, "We may by 1972 have to spend twice as much for higher education as we do for cigarettes! If we can only make clear to the American people what the task is, I feel sure they will tighten their belts and make the sacrifice."

Several of the nation's scientific and technological authorities called attention to the plight of today's colleges and universities in attempting to fulfill their role in the country's race with destiny.

Miami University's president, Dr. John D. Millett, Oxford, Ohio, stressed the point that one of higher education's basic objectives was the preparation of the "total individual." "We cannot give up our efforts to assist the student in understanding his life as a responsible human being, able to think effectively, to communicate thought, and to discriminate among values. It matters not that we so frequently fail in this lofty purpose. What matters is that we should never lose the vision of this noblest of educational goals."

Blasting a recent study that inferred the nation does not suffer from a shortage of engineers, Dr. William H. Miernyk reported for the first time results of a study committee of the American Society for Engineering Education. Pinpointing one of engineering's greatest shortages — that of qualified teachers — Dr. Miernyk estimated a need for some 9500 new teachers of engineering by 1966-1967. This figure alone is more than our total faculty resources, he said.

The problems of a university are many according to the scientific and engineering authorities. Ranging from finding the money to do the job expected, recruitment of faculties, how to plan for more scholarships and basically how to be intellectually "free" under "pressures" all plague the education of our scientists and engineers. Yale University's Dr. John S. Nicholar, president, Scientific Manpower Commission, offered two suggestions for the future.

First, he referred to a "virtually untapped resource, woman-power. In industry, government and university we have no legal statement that women should be kept in a world apart from that of man. The intelligence of females is equal, at least, to that of males. It should be employed on an equal and competitive basis in all creative work, and particularly at the present when the need for expansion is so great."

Turning to another dire American need, the Yale professor called for a cabinet post which would establish liaison between the country's three great agencies: education, industry and government. "Every major power except our own considers that education is important enough to have representation in the cabinet. In our own case it might also be wise to have another cabinet member in charge of science and technology. Surely the national security is to a larger extent bound up with the healthy development of all three branches of knowledge," he concluded.

More than 350 of the country's leading scientists, educators and business executives attended the three-day Chicago meeting.

Road Builders Study Aspects of Street Lighting

The Technical Committee on Highway Illumination of the American Road Builders' Association held their annual meeting on January 20, at the Sheraton-Park Hotel, Washington, D. C. Herbert A. Friede, chairman of the committee, moderated the session.

Program and speakers included:

Lighting Attitudes of State Highway Departments — E. C. Powers, Editor, Street and Highway Lighting Magazine.
Designing Lighting into New Highways — Stacy Standley, Street and Highway Safety Lighting Bureau, Cleveland.
A Utility Position in the Lighting of Highways — G. G. Wheeler, Northern States Power Co.
ALCOA Motion Picture on Lighting.
Panel Discussion—Warren Edman, Holophane Co.; John Lang, Union Metal Manufacturing Co.; E. B. Karns, Westinghouse Electric Corp.; A. D. Harrington, General Electric Co.; J. L. Shotwell, Bureau of Public Roads, Department of Commerce.

New Jersey Turnpike To Set Up Fog Test Area

The New Jersey Turnpike authorities will soon set up an actual road test area, covering half a mile of the turnpike, for studies of roadway lighting under fog conditions. The test installation will include overhead mounted down lights, and low side mounted continuous fluorescent reflector systems, among others, all of them adjustable to enable the authorities to try various arrangements of roadway lighting.

Interest in this was initiated following the attendance of General W. W. Wanamaker, Executive Director of New Jersey Turnpike authorities, at demonstrations last June at Penn State Universities and Michigan State University. These demonstrations covered results of studies of fog lighting conducted under the sponsorship of the Illuminating Engineering Research Institute. General Wanamaker was sufficiently impressed by the value of these researches that he immediately drafted a resolution to the New Jersey Turnpike

authorities, which was passed by the Commissioners. They have subsequently contributed funds to the Research Institute for further work on this research.

Their installation on the Jersey meadows will constitute a practical test on actual roadways under actual fog conditions, frequently a serious problem with them. Professor Marsh of Pennsylvania State will be a consultant to this test.

Discomfort Glare Studied By British-American Team

Dr. Ralph G. Hopkinson of the Building Research Station in England is heading up the researches on discomfort glare of large area sources and window areas, which are being sponsored by the Illuminating Engineering Research Institute at Cornell University, Ithaca, N. Y. Data of considerable importance are expected to emerge from these studies. The work will be a cooperative effort with the Building Research Station in England, with which Dr. Hopkinson is connected. R. C. Bradley, of the Engineering Department, Cornell, will serve as Dr. Hopkinson's assistant in carrying out the detailed testing.

Color and Building — Theme For ISCC Meeting

The Inter-Society Color Council has scheduled its 27th Annual Meeting at the Sheraton-Park Hotel, Washington, D. C. on March 25 and 26, with "Color and Building" the theme. The Tuesday session will include a joint meeting with the American Society for Testing Materials E-12 Committee, and an evening lecture by W. C. Granville, President of the ISCC, on "Color in European Buildings." During the day, members may visit the display of building products at the Federal Construction Products Center.

A symposium on "Color in the Building Industry," moderated by Waldron Faulkner, Program Chairman, will be featured on Wednesday afternoon, with the following topics and speakers:

Color in Ceramics — Dr. I. A. Balinkin, University of Cincinnati.
Color in Aluminum — J. R. Leary, Aluminum Co. of America.
Color in Porcelain Enamel — Herbert R. Spencer, Jr., Erie Enameling Co.
Color in Plastics — H. C. Doner, Libbey-Owens-Ford Glass Co.

The Wednesday evening banquet will feature Julian Garnsey speaking on "Color in the Building Industry."

Advance registration blanks may be obtained from Ralph M. Evans, Secretary, ISCC, Color Technology Division, Building 65, Eastman Kodak Co., Rochester, N. Y.

SCHEDULED EVENTS

February 20-21, 1958 — 14th Annual National Wiring Promotion Conference, Statler Hotel, Detroit, Mich.

March 2-5, 1958 — National Electric Sign Association, National Convention, Shamrock Hilton Hotel, Houston, Texas.

March 9-12, 1958 — First National Lighting Exposition, New York Coliseum, New York, N. Y.

March 25-26, 1958 — Inter-Society Color Council (27th Annual Meeting), Sheraton-Park Hotel, Washington, D. C.

April 10-11, 1958 — Northeastern Regional Conference, Statler Hotel, Hartford, Conn.

April 14-15, 1958 — East Central Regional Conference, John Marshall Hotel, Richmond, Va.

April 20-26, 1958 — Society of Motion Picture and Television Engineers, Ambassador Hotel, Los Angeles, Calif.

April 24-25, 1958—South Central and Southeastern Regional Conference, Lafayette Hotel, Little Rock, Ark.

April 28-29, 1958 — Southwestern Regional Conference, Hotel Washington Youree, Shreveport, La.

April 30, 1958 — Council Meeting, I.E.S., Hotel President, Kansas City, Mo. Members are free to attend meetings of Council as guests.

May 1-2, 1958 — Midwestern Regional Conference, Hotel President, Kansas City, Mo.

May 8-9, 1958 — Inter-Mountain Regional Conference, Whitman Hotel, Pueblo, Colo.

May 12-13, 1958 — South Pacific Coast Regional Conference, El Cortez Hotel, San Diego, Calif.

May 22-24, 1958 — Pacific Northwest Regional Conference, Multnomah Hotel, Portland, Oregon.

June 4-5, 1958 — Council Meeting, I.E.S., New York, N. Y. Members are free to attend meetings of Council as guests.

June 8-12, 1958 — National Association of Electrical Distributors (50th Anniversary Convention), Civic Auditorium, San Francisco, Calif.

June 9-13, 1958 — National Association of Electrical Distributors, 50th Annual Convention, San Francisco, Calif.

June 23-24, 1958 — Great Lakes Regional Conference, Sheraton Hotel, Rochester, N. Y.

June 23-27, 1958 — American Institute of Electrical Engineers (Summer General Meeting), Buffalo, N. Y.

August 17-22, 1958 — Illuminating Engineering Society (National Technical Conference), Royal York Hotel, Toronto, Canada.

August 19-22, 1958 — American Institute of Electrical Engineers, Pacific General Meeting, Sacramento, Calif.

September 22-25, 1958 — Institute of Traffic Engineers (Annual Meeting), McAllister & Columbus Hotels, Miami, Florida.

October 8-10, 1958 — Canadian Electrical Manufacturers Association (14th Annual Meeting), Sheraton Brock Hotel, Niagara Falls, Canada.

October 10-11, 1958 — International Association of Electrical Inspectors (Canadian Section), Toronto, Ont.

October 13-15, 1958 — National Electronics Conference, Inc., Hotel Sherman, Chicago, Ill.

October 19-24, 1958 — Society of Motion Picture and Television Engineers, Sheraton-Cadillac Hotel, Detroit, Mich.

October 20-24, 1958 — National Safety Council (46th National Safety Congress & Exposition), Chicago, Ill.

October 27-31, 1958 — American Institute of Electrical Engineers (Fall General Meeting), Pittsburgh, Pa.

November 10-14, 1958 — National Electrical Manufacturers Association (Annual Meeting), Traymore Hotel, Atlantic City, N. J.

November 18-20, 1958 — American Standards Association (9th Annual Conference on Standards), Hotel Roosevelt, New York, N. Y.

January 19-23, 1959 — American Institute of Electrical Engineers (Winter General Meeting), New York, N. Y.

Plans Advance for National Lighting Exposition

The First National Lighting Exposition has announced that more than 180 major exhibits have been scheduled by manufacturers and key trade associations for the lighting industry's New York Coliseum show next month.

Harold Meyer, President of National Lighting Expositions, has said that advance attendance reports indicate that more than 10,000 contractors, architects, designers and builders from throughout the nation will attend the March 9-12 show.

Pre-registration also has been heavy, Mr Meyer said, for a series of ten special symposiums covering major categories of lighting techniques and installations. Among those who will conduct the symposiums are Thomas Smith Kelly, lighting consultant of New York City (residential); Professor Stanley McCandless of Yale University (theatrical); Dr. Frederick Hill, Assistant Superintendent of Schools, Minneapolis (school); John Neidhart, The Miller Co., Meriden, Conn. (office); and Peter Muller-Munk, of Peter Muller-Munk Associates, Pitts-

(Continued on page 14A)

LITECONTROL'S

New-As-Tomorrow Lens Ceiling

Solves Control Room Lighting Problem TODAY

The Problem:

To provide the best possible lighting in quantity and quality for the critical seeing tasks of reading meters accurately over long periods.

The Solution: Litecontrol's standard lens ceiling panels. These were chosen to provide 230 foot-candles of the most comfortable lighting you have ever seen. (The perimeter recessed lighting next to the control board was furnished by the Holophane Company.) This is truly lighting of the future — available today with Litecontrol fixtures, using Holophane's acrylic PRISMALUME lenses.

The luminous ceiling provides high intensity and low brightness far beyond the average lighting job. Combined with high reflectance ceiling, wall, and floor finishes, it reduces contrast to a minimum and, by solving the glare problem, aids work efficiency and comfort. No wonder the installation was a prize winner in the 1957 International Lighting Competition — Electric Utilities Division. Yes, and the operators are enthusiastic, also.

This type of lighting can be used effectively on *your* next installation — in a control room or elsewhere. Think of LITECONTROL for *inexpensive* quality lighting for your next store, office, school or other public building job.

Installation: Connecticut Valley Power Exchange, Bloomfield, Conn.
Architect & Engineer: Alderman & MacNeish, West Springfield, Mass.
Lighting Consultant: John F. Dougherty, Hartford Electric Light Co., Hartford, Conn.
General Contractor: Industrial Construction Co., Hartford, Conn.
Electrical Contractor: T. J. Martin Electric Co., Hartford, Conn.
Area: System Operators' Room
Finish: Floor — 47% R.F. off white. Desks — gray, mist-gray tops. Walls — light tan. Control Boards — medium dark green (for contrast). Distributing tapes — multi-colored. Ceiling — marbleized white.
Fixtures: Litecontrol standard lens ceiling panels with Holophane #6024 acrylic lenses, and F40T12/RS rapid start lamps, 12" on centers.
Intensities: All lamps on —
Average room intensity 30" from floor — 206 foot-candles
Average intensity on desk tops — 230 foot-candles
With half the lamps on, these figures become 120 and 135 foot-candles, respectively.
Average vertical intensity on Distribution Board, 91.9 ft.-C
Average vertical intensity on Instrument Board, 89.3 ft.-C
Variation in readings, 12" intervals down Boards, 81 to 95 ft.-C

Brightness Readings: Across axis of lamps — Lens Ceiling —
15° down from horizontal, 108 foot-lamberts
30° down from horizontal, 276 foot-lamberts
45° down from horizontal, 497 foot-lamberts
Along axis of lamps —
15° down from horizontal, 140 foot-lamberts
30° down from horizontal, 145 foot-lamberts
45° down from horizontal, 158 foot-lamberts

LITECONTROL
Fixtures
KEEP UPKEEP DOWN
LITECONTROL CORPORATION,
36 Pleasant Street, Watertown 72, Massachusetts

DESIGNERS, ENGINEERS AND MANUFACTURERS OF FLUORESCENT LIGHTING EQUIPMENT DISTRIBUTED ONLY THROUGH ACCREDITED WHOLESALERS

(Continued from page 11A)

burgh (industrial). Symposiums are also scheduled in the fields of merchandising, street and highway, public institutions, light sources and light utilization.

Mr. Meyer said that response to 500,000 invitations mailed recently has been "highly gratifying" and that special travel arrangements have been made with American Airlines to handle the large number of out-of-town persons. If indications of heavy attendance from key cities in the Midwest and Far West hold true, he added, special group flights will be set up.

Broad categories represented by exhibits at the exposition, sponsored by the Lighting Lamps and Electrical Manufacturers Salesmen's Association, Inc., will be home, church, street, factory, theatre, highway, design, rural laboratory, indoor display, animal husbandry, sign, refinery, school, store, airport, office, hospital, institutions, ship, outdoor display, holiday, stage, mine, port and dock.

From the Historical Committee's Scrapbook

The Last Gas Lighting in Manhattan

One lone residence still remains in New York City which is wholly lighted with gas. No electricity has flowed into this house since it was built, in 1888.

Do not be misled that poverty or ignorance has brought this about! To the contrary. Among former owners were Lorenzo Delmonico, William Astor, and August Belmont, and the present owner is a famous legal and cultural leader. Genteel and aristocratic living has characterized this four-story New York brownstone residence for these past seventy years.

The house is delightful to visit. It takes one back in memory to a nearly forgotten era of city history. Throughout are hand-carved mahogany woodwork, parquet floors, wide fireplaces, Paisley shawls across four-poster beds, and heavy velour drapes, all "lighted" by open gas flames, not even the "modernized" fishtail burners. Chandeliers in the parlor are of exceptionally lovely Dutch or Flemish brass designs, each with a dozen or more burners like birthday cake candles. They are not efficient, of course; nevertheless, the light has a quality of softness that seems to make amends for its shortcomings.

Down in Greenwich Village are two gas street lamps, and one lone old-timer lingers in front of the "Gas-Light Club" on 56th Street. However, for all practical purposes, this method of lighting has gone the way of the Betty Lamps and the whale-oil wick burners. We bid them farewell with a touch of nostalgia. We shall not see their like again.

Plastics in Illumination — Topic Of BRI March Conference

The first major conference of the Building Research Institute in 1958, "Plastics in Building Illumination: Daylight and Electric Sources" has been scheduled for March 5 and 6 at the University of Houston, Houston, Texas. The conference is an activity of the BRI Plastics Study Group, formed in 1954 as a result of the increasing importance of plastics in the building industry.

The program will consist of three sessions:

Objectives of Building Illumination — Performance Requirements, Use of Daylight, Use of Electric Light.

Plastics Applications — Materials Available, Daylight Control, Prismatic Control of Electric Light, Diffusion Control of Electric Light, Luminous Ceilings.

Future Applications — Light Transmitting Products, Multi-purpose Elements, Quality Control.

A feature of the meeting will be a presentation by the architecture students of the University of Houston of the results of a project executed in cooperation with the Plastics Study Group.

The Building Research Institute is a member of the National Academy of Sciences.

Further information on this meeting may be secured from Harold Horowitz, Technical Secretary, BRI, 2101 Constitution Avenue, Washington 25, D. C.

CHECK for $10,000 is presented to A. F. Wakefield (standing left), Chairman of the Board of Trustees of the Illuminating Engineering Research Institute, by I.E.S. President Kirk M. Reid. Presentation was made during the December 12 meeting of the I.E.S. Council. Funds are administered by the I.E.R.I. for basic lighting research.

Annual Winter Courses Scheduled by C.L.I.

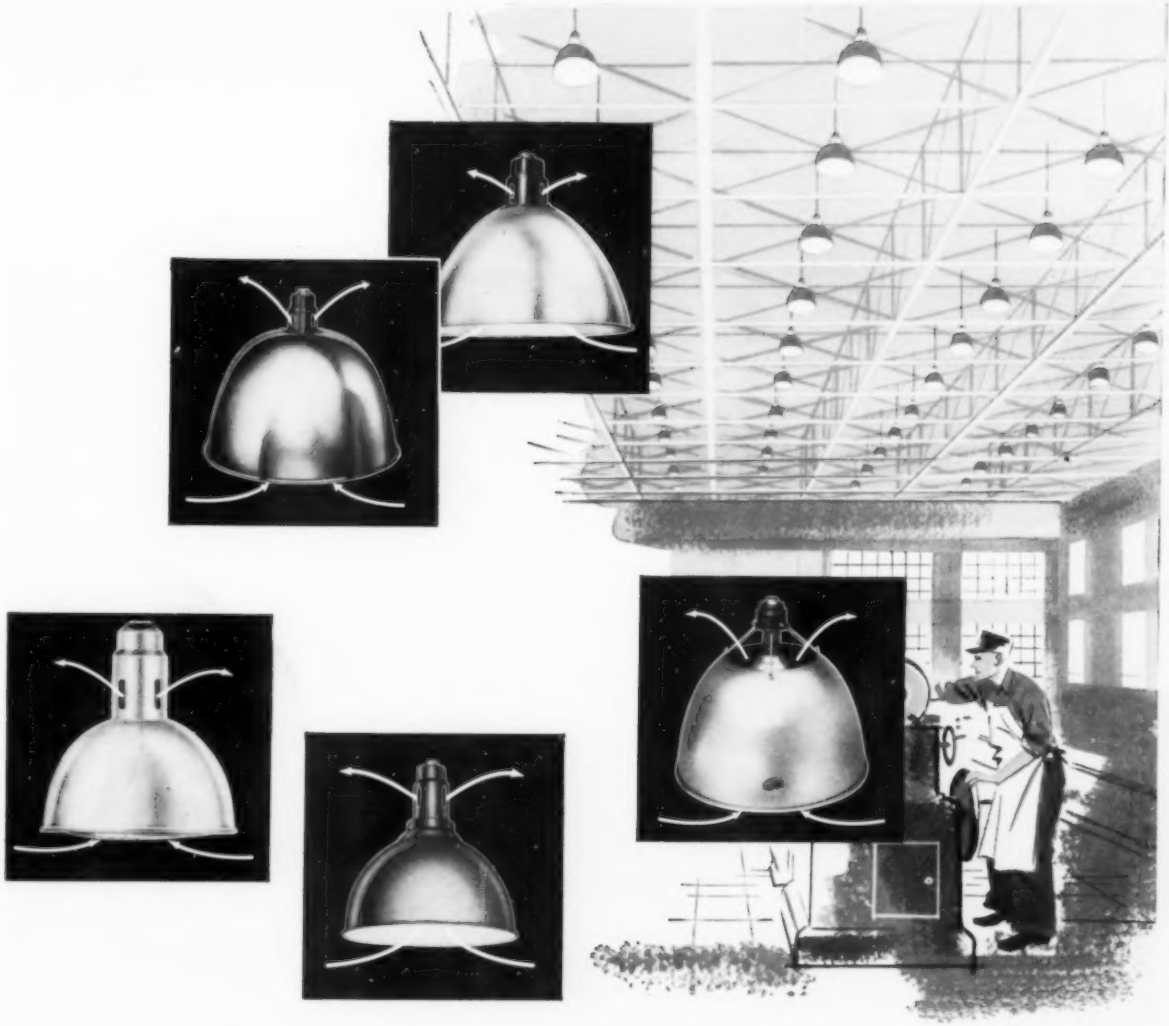
The yearly winter courses given by the Chicago Lighting Institute in cooperation with the Chicago Section of IES and the Illinois Institute of Technology, began on January 6, at the Institute's new headquarters: 140 South Dearborn Street, Chicago.

Raymond E. Wozniak is the Instructor for the fundamentals course, both lecture —1½ hour sessions on Monday, and laboratory — 1½ hour periods on alternate Thursdays.

Wiring Design — No. 2, under the direction of Frank R. McShane meets on Tuesdays from 6:30 to 8.

R. R. Lusk is the Lecturer for Light-

(Continued on page 17A)



ABOLITE'S MODERN AIR-SWEPT DESIGN

reduces maintenance costs on high and medium bay installations

Air circulating through Abolite fixtures with *slotted neck* or *uplight* design are swept clean of dulling dust. Maintenance costs are kept down to a bare minimum.

NEW UPLIGHT FIXTURES FOR HIGH BAY

Abolite's uplight fixtures direct a portion of the light upward, eliminate sharp contrasts and glare by washing out deep background shadows. Abolite has the *right* fixture for every high or medium bay installation —*both* Alzak aluminum and porcelain enamel fixtures for all type 400 and 1000 watt mercury lamps; and for 300-1500 watt incandescent lamps.

ABOLITE *Lighting*

THE JONES METAL PRODUCTS COMPANY
West Lafayette, Ohio

Write for
FREE Brochure

This brochure will be helpful to you whether you design, specify or buy. It contains fact and performance data on all Abolite fixtures for high and medium bay lighting. Tear out coupon and send for your copy now.

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Gentlemen:
Please send me your brochure on Incandescent and Mercury fixtures for Industry. No obligation, of course.

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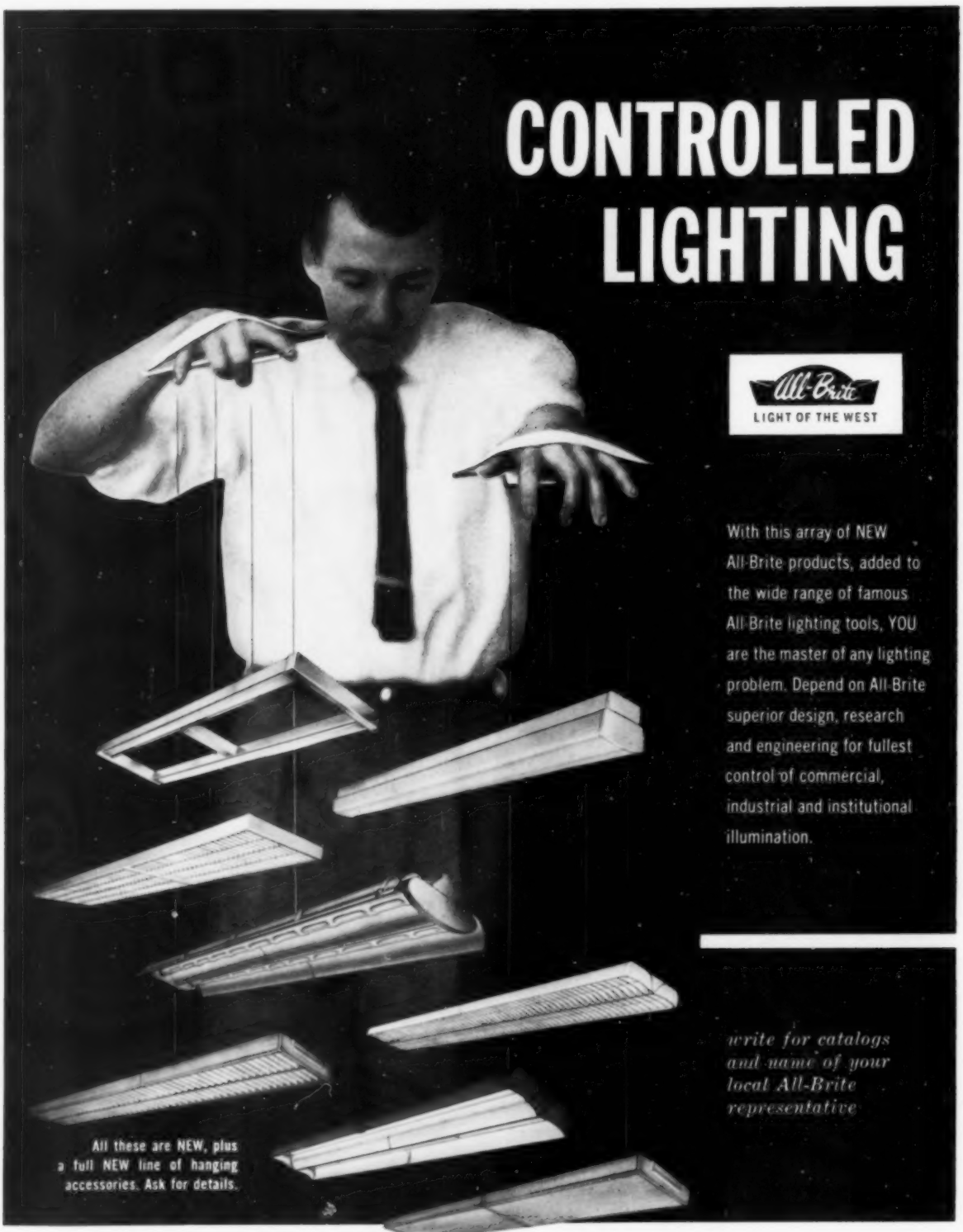
CONTROLLED LIGHTING



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LIGHT OF THE WEST

With this array of NEW All-Brite products, added to the wide range of famous All-Brite lighting tools, YOU are the master of any lighting problem. Depend on All-Brite superior design, research and engineering for fullest control of commercial, industrial and institutional illumination.

All these are NEW, plus a full NEW line of hanging accessories. Ask for details.

write for catalogs and name of your local All-Brite representative

FLUORESCENT FIXTURES OF CALIFORNIA

352 SHAW ROAD
SOUTH SAN FRANCISCO, CALIF.

PLANTS ALSO IN LOS ANGELES; PORTLAND, OREGON; AND VANCOUVER, B. C., CANADA

(*Continued from page* 14A)

ing Design Problems, 1½-hour session on Thursdays, with Mr. Wozniak conducting laboratories on alternate Wednesdays.

Tuition for each of the three courses is $25.

Carl W. Zersen, Managing Director of the Institute, has announced that in the fall session of classes which started on October 14, there were 51 students enrolled in the Lighting Course and 46 in the Wiring Course.

Three New Chapters Chartered

At the December 12 meeting of the I.E.S. Council, Charters were approved for three new Chapters. These are:

South Plains Chapter, with headquarters at Lubbock, Texas. Recommended by R. K. Lothrop, Vice-President of the Southwestern Region.

Coastal Bend Chapter, with headquarters at Corpus Christi, Texas.

Forest City (London) Chapter, with headquarters at London, Ont. Recommended by J. Carl Wilson, Vice-President of the Canadian Region.

Approval of these charters brings the total number of I.E.S. Groups to 80.

ASHAE Annual Meeting Presents Varied Program

The meeting of the American Society of Heating and Air-Conditioning Engineers on January 27 and 28 at the Penn-Sheraton Hotel, Pittsburgh, included sessions on the Utilization of Solar Energy, High Temperature Water, and School Heating, Ventilating and Air-Conditioning. In addition to the technical papers presented at the conference, delegates heard addresses by David L. Lawrence, Mayor of Pittsburgh and Allison R. Maxwell, Jr., president of the Pittsburgh Steel Co.

FINAL meeting of the Milwaukee Lighting Fundamentals Course, at which 66 certificates were awarded.

Milwaukee Fundamentals Course Awards Certificates to 66

A repeat course in Lighting Fundamentals, designed for architects and electrical contractors, was co-sponsored from October 14 to December 9 by the Milwaukee Section of IES and the Wisconsin Electric Power Co. Certificates for completion of the course were awarded to 66 of the 75 who had registered for classes at the Engineers Society of Milwaukee Building.

Each of the two-hour sessions was conducted by two speakers, the first discussing lighting design, and the second showing the application of lighting by means of colored slides. Fourteen IES members served as instructors, and I. L. Illing, Fellow of IES, formerly of Wisconsin Electric coordinated the sessions.

The course, which was first given in 1956 as part of the IES 50th anniversary celebration, was repeated because of its original success.

Program and speakers were:

October 14 — New Developments in Light Sources — William Lowell, General Electric Co. and William Kennedy, Sylvania Electric Products, Inc.

October 21 — Lighting Design Methods — I. L. Illing and C. N. Laupp, Wisconsin Electric Power Co.

October 28 — Lighting for Merchandising — Martin Weiss and E. H. Schaefer, Wisconsin Electric Power Co.

November 4 — Office Lighting Design — B. R. Bunn, Westinghouse Electric Supply Co. and Ed Schnoll, Standard Electric Supply Co.

November 11 — School Lighting Techniques — George Craft, Wisconsin Electric Power Co. and C. N. Laupp, Wisconsin Electric Power Co.

November 18 — Church and Public Building Lighting — A. B. Rowold, A. B. Rowold Co. and I. L. Illing.

November 25 — Industrial Lighting Practice — T. D. Dustin, A. C. Electric, Inc. and William Kuhnke, Wisconsin Electric Power Co.

December 9 — Outdoor Lighting Applications — Robert Present and M. H. Bruesewitz, Wisconsin Electric Power Co.

The final meeting was highlighted by a delicious steak dinner, broiled (on a 12 kw electric broiler) and served by the instructors and employees of Wisconsin Electric.

I.E.S. National Technical Conferences

1958 — August 17-22 — Royal York Hotel, Toronto, Ontario

1959 — September 7-11 — Hotels Fairmont and Mark Hopkins, San Francisco, California

1960 — September 11-16 — Penn Sheraton Hotel, Pittsburgh, Pennsylvania

1961 — September 24-29 — Chase Park Plaza Hotel, St. Louis, Missouri

1962 — September 9-14 — Statler-Hilton Hotel, Dallas, Texas

Atlanta Residence Lighting Forum Christmas Lighting Contest

A feature of the December meeting of the Residence Lighting Forum in Atlanta, Ga., was a contest for lighted Christmas decorations. Numerous ingenious lighting ideas came forth, with prizes going to three of them. Both first and third places were won by Mrs. Evelyn Harris; her two entries are

(*Continued on page* 18A)

SHOW window display of two winning entries in Atlanta Residence Lighting Forum's Christmas competition.

(*Continued from page* 17A)

shown in the accompanying photograph, as displayed in the show windows of the Georgia Power Co.

The winning display was a shadow box made from an old picture frame with a removable back, containing a Christmas scene. The box was illuminated with tubular lamps, and the whole arrangement may be changed for other use throughout the year.

Second place was an outdoor display of a simulated stained glass window, by Homer Youngblood. Third place was a white chicken feather Christmas tree. This was made by sticking white chicken feathers into a stryogoam base, which was decorated with glitter and miniature colored bulbs.

Another project now under consideration by the Atlanta Residence Lighting Forum will be a two year program on a permanent garden lighting area. This will be a cooperative affair between the owner and the Forum and will be in a place easily viewed by the public.

Standard Amp Stays on the Mark

A recent experiment at the National Bureau of Standards has shown that the standard ampere maintained by the Bureau has drifted no more than a few parts per million in the last 15 years. Such a small apparent change may well be due to slight errors in measurement so that the standard ampere may actually have remained perfectly stable since its original evaluation in 1942.

Since current is transitory, the primary standard ampere cannot be kept in the form of a material object such as the standard cells that maintain the volt or the standard resistors that maintain the ohm. Each time the standard ampere is required, it must be obtained anew from the standard volt and the standard ohm by use of Ohm's law. However, a gradual change might sometimes occur in the standard cells or resistors. One method of checking their stability is to compare the standard ampere derived from them with the "absolute" ampere; that is, the ampere obtained experimentally in terms of the mechanical units of length, mass and time.

For Possible Assistance on That April 15 Deadline

The following information was received by the Engineers Joint Council, confirmed by their legal counsel, and transmitted, as being of possible help, to members of I.E.S. and similar engineering societies.

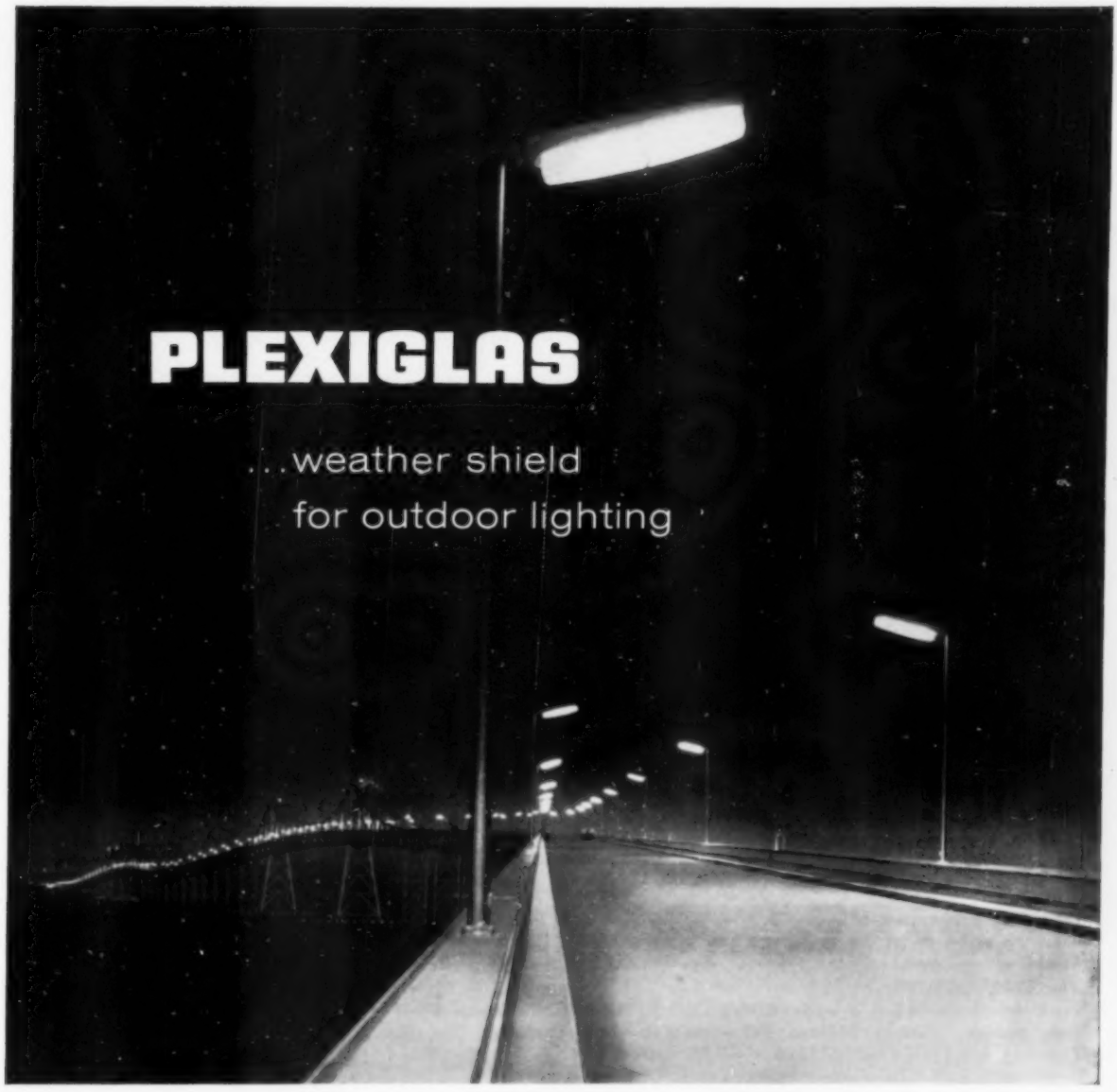
The Internal Revenue Service under ruling 55-4, I.R.B. 1955-1 states that a taxpayer "who gives his services gratuitously to an association, contributions to which are deductible" under the relevant provisions of the Code "and who incurs unreimbursed traveling expenses, including the cost of meals and lodging, while away from home in connection with the affairs of the association and at its direction may deduct the amount of such unreimbursed expenses in computing his net income;" subject, however, to the limitation in respect to all gifts made to exempt organizations of our type; namely, that the total amount of such gifts made in any one year may not exceed 20 per cent of the donor's gross income for such year. This limitation means that while such expenses are deductible they are included with other gifts in computing the 20 per cent limitation.

ABOUT PEOPLE

New executive appointments at the policy, administrative and operations levels, effective January 1, 1958, were announced by the Westinghouse Electric Corp. at the December meeting of the board of directors in New York City. **Gwilym A. Price** who has been president of the firm since 1946, and chairman since 1955 becomes chairman of the board. **Mark W. Cresap, Jr.,** former executive vice-president is the new president. **E. V. Huggins** who has been vice-president and corporate secretary is now chairman of the executive board of directors and vice-president. **John D. Hodnette,** vice-president and general manager was elected executive vice-president. **George G. Main** continues as treasurer and is also vice-president—finance. **Francis E. Dalton** received the post of controller. **Carlisle P. Myers** continues as general counsel and assumes the position of corporate secretary.

General Electric Co. has announced several promotions and additions to their staff. Effective January 1, **Charles M. Heiden** assumed the post of manager of the Research Application Department at the G. E. Research Laboratory. Mr. Heiden replaces **Dr. Lyman R. Fink** who recently was named general manager of GE's X-Ray Department in Milwaukee, Wis. **George E. Matilo** has been appointed specialist for retail lamp sales through utility companies, by the Large Lamp Department. Mr. Matilo will cooperate with the electric service companies to help them establish residential lighting promotions as part of an industry-wide program on home lighting. **Harry W. Bourgeois** has been named district sales manager in Delta Large Lamp sales district, with headquarters at New Orleans. **Gordon E. Brown,** former manager of Delta district has been transferred to South Central sales district, with headquarters at Memphis. Mr.

(*Continued on page* 20A)



Hundreds of fluorescent luminaires light the new Richmond-San Rafael bridge over San Francisco Bay. Durability is a requisite of these units. A vital component in their rugged construction is the large shield, molded of PLEXIGLAS® acrylic plastic. This shield protects lamps, sockets and ballasts from high winds, low temperatures, corrosion, dirt and bad weather.

Great strength . . . light weight . . . proven weatherability . . . freedom from discoloration . . . these are the reasons PLEXIGLAS shields are essential to top performance in outdoor lighting. Be sure the equipment you select—for streets and highways, parking lots, service stations, bridges—includes the advantages of PLEXIGLAS. We will be glad to send you the names of manufacturers who use this quality material in their luminaires, and a copy of our brochure "PLEXIGLAS for Outdoor Lighting"

Canadian Distributor: *Crystal Glass & Plastics Ltd., 130 Queen's Quay East, Toronto, Ontario, Canada.*

Chemicals for Industry

ROHM & HAAS COMPANY

WASHINGTON SQUARE, PHILADELPHIA 5, PA.

Representatives in principal foreign countries

(*Continued from page* 18A)

Brown replaces the late **George W. Ellis,** who died on October 23.

Clarence J. Berry, Manager of the Lighting Service Department, Baltimore Gas and Electric Co., retired January 1, after nearly twenty-five years with the utility. Mr. Berry, a past Regional Vice-President of the East Central Region, I.E.S., has been active in both local and national committee work.

E. W. Conover, Research Engineer, with Fenestra Inc., Detroit, Mich., retired December 31. Mr. Conover is an active member of the I.E.S. Daylighting Committee and its subcommittees, and has had many papers published in I.E.

Globe Lighting Products, Inc., Los Angeles, has announced the appointment of **René B. Marxheimer** as laboratory engineer for Design and Development Research. Mr. Marxheimer was most recently with the California State Department of Public Works, Division of Highways. He has done considerable research work on roadway visibility and associated lighting problems with Professor Dan Finch of the University of California at Berkeley.

PRACTICAL Illumination Course in session (above) in San Jose Chapter. The course, a series of ten meetings, was also held on other days of the week in Stockton, Sacramento and San Francisco (see November 1957 I.E., page 35A). The Golden Gate Section sponsored all four series. Awarding diplomas to graduates of the San Jose section (below) are C. W. Macy, Chairman, Golden Gate Section; William Addison, Education Committee Chairman, San Jose Chapter; and Frank Duhme, Education Committee Chairman of the Golden Gate Section.

Cyril Ainsworth, technical director of the American Standards Association has been appointed deputy managing director of the association. **J. W. McNair,** assistant technical director, succeeds Mr. Ainsworth as technical director. Mr. McNair was also appointed assistant secretary. **Vice-Admiral George F. Hussey, Jr.** was re-elected managing director of the association.

Sunbeam Lighting Co., Los Angeles, has added three new sales representatives to their force. **J. P. Tendick** of Brookfield, Wisconsin will cover the territory of Wisconsin and the Upper Peninsula of Michigan. Mr. Tendick was formerly branch manager for Westinghouse Electric Supply Co. In Minnesota, North and South Dakota, **Warren D. Anderson** Sales Co. will represent Sunbeam, and **Paul F. Kyack,** Inc. of Philadelphia will be responsible for Philadelphia, Eastern Pennsylvania, Southern New Jersey and Delaware.

E. R. Needles (ASCE) and **O. B. J. Fraser** (AIME) were unanimously elected president and vice-president of the Engineers Joint Council for 1958, by the Board of Directors. **E. Lawrence Chandler** continues as treasurer, **E. Paul Lange** as secretary and **L. K. Wheelock** as assistant secretary. The officers were installed on January 10.

E. L. Rolls, former district representative for American Machine and Foundry Co. has been appointed executive director of Federal Lighting Corp., Cleveland, Ohio.

William T. Fowler has been appointed sales specialist to the lamp industry for the Lighting Sales Department of Corning Glass Works, in the New York and Philadelphia areas.

The new manager of sales at Pacific Union Metal Co., Los Angeles, is **Paul Ogilvie.** Mr. Ogilvie, who has been with Pacific Union for four years was formerly associated with Pacific Gas and Electric Co.

John C. Virden Co., Cleveland, has announced the appointment of **Donald S. Gleason** as sales representative in the states of Washington and Oregon. Mr. Gleason will work closely with **Jib Sawyer,** Virden's Western Manager.

Construction of a new factory and warehouse building in the 1500 block of Rollins Road, Burlingame, Calif., has been announced by the Benjamin Elec-

(*Continued on page* 23A)

20TH FLUORESCENT ANNIVERSARY ANNOUNCEMENT

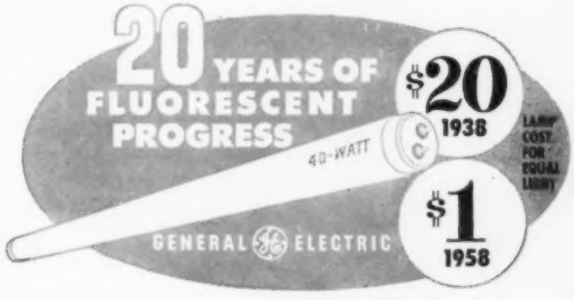
His face lighted by the pile of "Bonus Phosphors", General Electric's W. C. Martyny developed the process that gives your customers more light from the start . . . more light throughout the long life of the G-E lamps.

This new General Electric Bonus Phosphor gives your G-E Fluorescent Lamp customers 7 to 9% more light . . . at no added cost!

Because G.E. has found a way to throw out the small—and least efficient—phosphor particles and save just the bigger, brighter ones, your customers now get even more for all their lighting costs when they use G-E 40-watt fluorescent lamps!

What Does This Mean To Them? In factories and offices: added light worth ½ to twice their yearly lamp purchases. In stores and schools: 2 to 3 times as much added light as their yearly lamp purchases.

This "Bonus Phosphor" is now available in the 40-watt and new Power-Groove—and will soon be used in all G-E fluorescent lamp types. For the complete "Bonus Phosphor" story—see or write your local General Electric Large Lamp Salesman.



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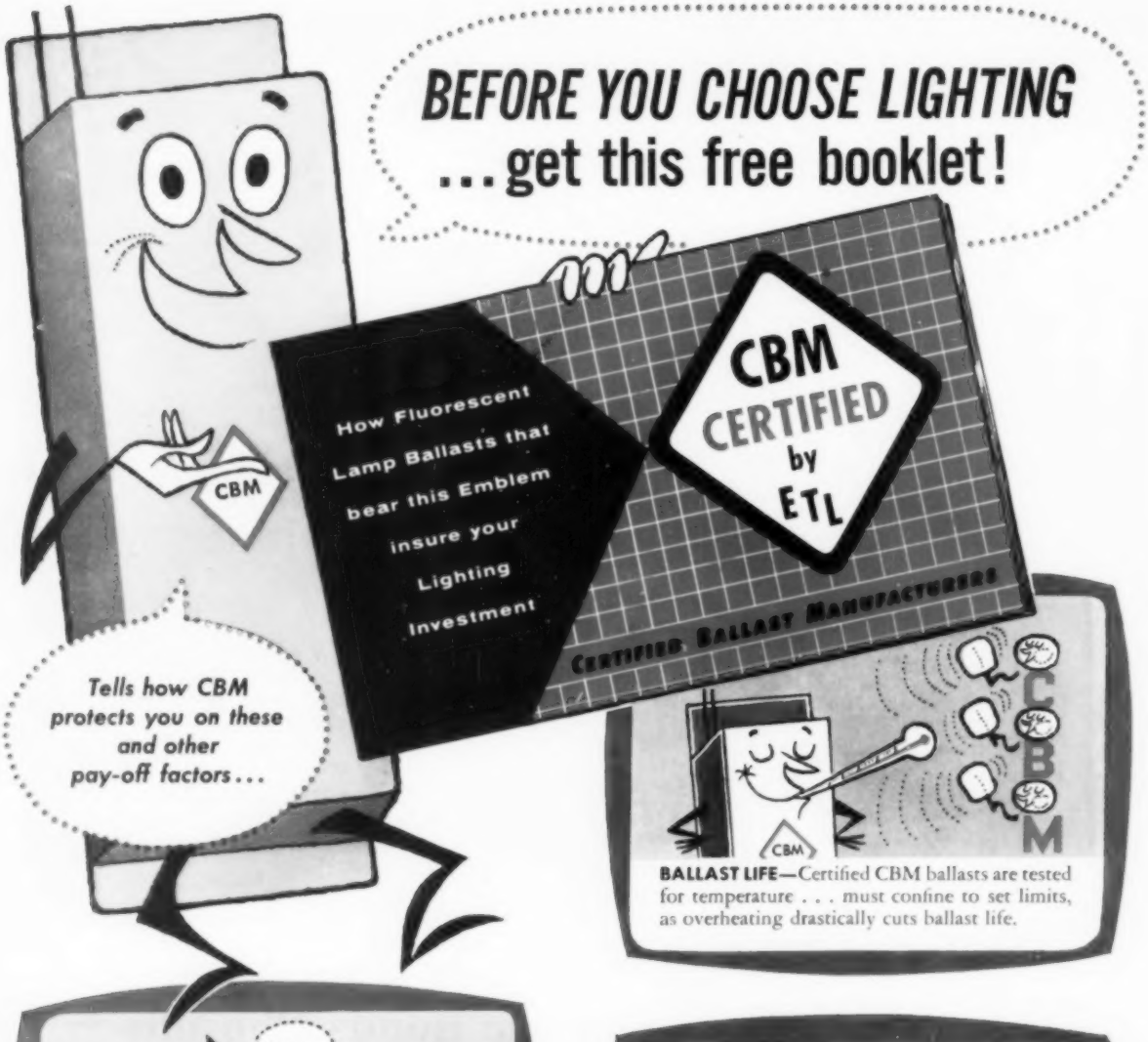
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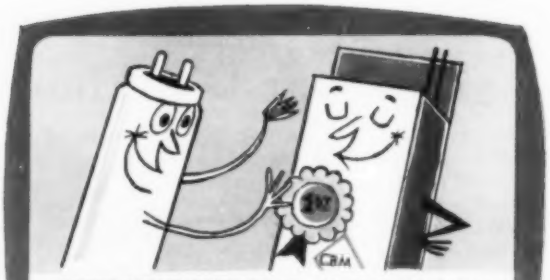
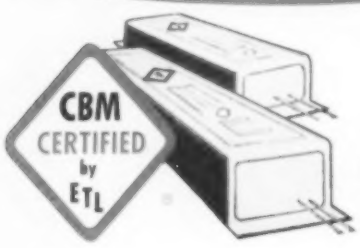
How Fluorescent Lamp Ballasts that bear this Emblem insure your Lighting Investment
CBM CERTIFIED by ETL
CERTIFIED BALLAST MANUFACTURERS
Tells how CBM protects you on these and other pay-off factors...
CBM

BALLAST LIFE—Certified CBM ballasts are tested for temperature . . . must confine to set limits, as overheating drastically cuts ballast life.

QUIET OPERATION—CBM specifications require a ballast to be well-designed mechanically and electrically, so that it will operate quietly and not create objectionable noise.



RATED LIGHT OUTPUT—Certified CBM ballasts are "tailored to the tube" . . . assure rated light output, steady light, peak lighting performance.



Send for this free booklet and learn how these factors and 11 others help insure your lighting investment when you buy fixtures equipped with Certified CBM ballasts.

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Participation in CBM is open to any manufacturer who wishes to qualify

CBM-6-U

(Continued from page 20A)

tric Manufacturing Co., Des Plaines, Ill. Establishment of these facilities near San Francisco marks the company's first entry into branch factory operations.

William A. Feuillan has returned to the faculty of the College of Business Administration, Loyola University. Mr. Feuillan was Chairman of the New Orleans Section in its charter year as a Chapter, and has also served as Vice-President of the Southern Region of I.E.S.

Robert Thallon of San Mateo has been signed to represent The Wakefield Co. in San Francisco.

Obituary

Dr. Willis R. Whitney, founder of the General Electric Research Laboratory, died December 9 of a heart attack, at his home in Schenectady. He was 89.

An honorary vice-president of General Electric, Dr. Whitney had served as director of the Research Laboratory for 32 years, until his retirement in 1932. Since that time he had continued research as consultant to the laboratory.

Among the many discoveries and developments made under his direction are important improvements in incandescent lighting, the harnessing of the cathode ray for radar and television use, development of high-voltage x-ray apparatus and a submarine detector used effectively in World War I. The first metalized carbon filament for incandescent lamps came as a direct result of an experiment by Dr. Whitney. Later his laboratory found a way to produce ductile tungsten for incandescent filaments.

Dr. Whitney was a Member Emeritus of I.E.S., a member of the National Academy of Sciences; National Research Council, American Chemical Society, American Electrochemical Society, and many other scientific organizations. He was the recipient of the Edison Medal, the Willard Gibbs Medal, Franklin Medal, the gold medal of the National Institute of Social Sciences, the Chandler Medal, the Perkin Medal and the medal of the Industrial Research Institute. He was the author of many scientific publications in such fields as corrosion of iron, solubility determinations, colloids, alloys, chemistry of light, carbon brushes, catalysis phenomena, vacua and electrochemistry.

Deaths

Lester T. Allen, Oil Capital Section
M. J. Cleary, St. Louis Section
Harold S. Moody, Southern California Section

BOOKS AND PAMPHLETS

*Books whose reviews are marked * are available for inspection at I.E.S. Headquarters Office, Technical Department.*

***Nickerson Color Fan,** distributed by American Horticultural Council, published by Munsell Color Co. $5.00.

The purpose of this maximum chroma, 40 hue "color fan" is to provide an inexpensive, easy to handle color chart that is useful for identification, specification and for color harmony studies in horticulture and other fields. The fan, which measures 1¾" x 7½" when closed, has a hard cover and contains 40 individual leaves, each of a different Munsell hue. There are a total of 262 color samples, each of which is identified by the popular color name and Munsell color designation.

The fan was developed by Dorothy Nickerson, color technologist, United State Department of Agriculture, with the cooperation of the Munsell Color Foundation. It is available from Donald Wyman, Secretary A.H.C., Arnold Arboretum, Jamaica Plain 30, Mass.

***Geometrical and Physical Optics,** by R. S. Longhurst, published by Longmans, Green and Co., Inc., 55 Fifth Ave., New York 3, N. Y., 1957, 534 pages, illustrated and indexed. $12.00.

This British book deals with such subjects as the geometrical theory of perfect optical systems, the wave theory of light, interference, diffraction, the physical theory of image formation, aberrations and optical instruments, polarization, visual optics and color, photometry, and the electromagnetic theory of light.

It is the author's intent that this work be a sufficiently detailed account of the subject to make the book useful to the more advanced students in physics, yet of use to the reader whose background is somewhat limited in mathematics. Most of the more mathematical parts of the book have been put in separate sections and can be omitted by the less advanced student.

The author is Senior Lecturer in Physics at Chelsea Polytechnic, London, England.

***Wiring Manual for Home and Farm,** by A. Carl Bredahl, published by McGraw-Hill Book Co., Inc., 330 West 42nd St., New York 36, N. Y., 221 pages; illustrated and indexed. $4.95.

This book is intended as a guide to the modern practice of design in electric light and power distribution for the house and farm. It deals with various types of equipment such as those used for heating, lighting, control and communications and how to calculate the size of the wiring system to properly carry the electrical loads. It is not a book on how to install material making up the wiring system.

The author, who is Director of Technical Services at Westinghouse Electric Corp., has intended this work for architects, engineers, builders, electrical contractors, or those who plan new designs or make changes in existing distribution systems in the home or on the farm.

***Standard Handbook for Electrical Engineers,** Archer E. Knowlton, Editor-in-Chief, McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1957, Ninth Edition, 2230 pages, illustrated and indexed. $19.50.

The purpose of this new edition is to record for reference the advances in engineering techniques since the last edition (1948). In doing this the treatment of certain long-standing and now obsolete practices has been reduced.

The authors, Walter Sturrock and Karl A Staley, both of the General Electric Co., have given the illumination section a new treatment with the application engineer in mind. Titles of the major portions of the 91-page section are: Radiant Energy and Light, Units and Conversion Factors, Standards of Luminous Intensity, Characteristics of Electric Lamps, Arc Lamps, Design of Lighting Accessories, Luminaires, Artificial-Daylight Equipment, Residence Lighting, The Candlepower Distribution Curve, Quantity and Quality of Illumination, Design of the Lighting System, Floodlighting Design and Procedure, Economics of Lighting, Radiant-Energy Detectors. Photoelectric Photometry, Portable Photometers, and Colorimetry and Spectrophotometry.

***Mathematics for Science and Engineering,** by Philip L. Alger, published by McGraw-Hill Book Co., Inc., 330 West 42nd St., New York 36, N. Y., 1957, 360 pages, illustrated and indexed. $6.95.

It is the intent of this book to serve as a reference for engineers, scientists and others as well as a short integrated course for students in colleges, technical institutes and industrial training programs. Beginning with arithmetic, it covers such subjects as trigonometry, algebra, calculus, differential equations and probability.

This book is a revision of *Engineering Mathematics* by Charles P. Steinmetz.

(Continued on page 38A)

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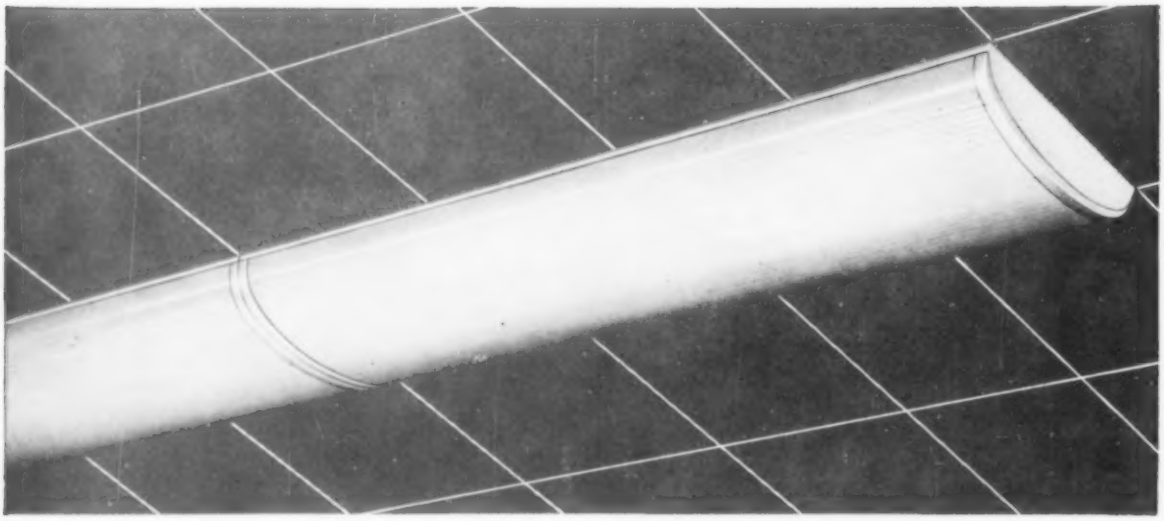

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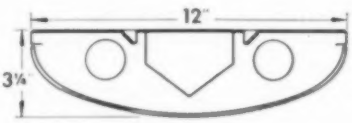

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These booklets are the complete, standard recommendations for lighting the prescribed areas, and are among the most comprehensive and important of all Society publications. As indicated, some of these recommendations are the work of committees of the American Standards Association, with collaboration by appropriate committees of the I.E.S. All have the approval of the Council of the Illuminating Engineering Society, and are the latest official I.E.S. recommendations.

In general, the information contained in these Recommended Lighting Practices covers completely the area shown in the title. Included in the data are suggested types of lighting systems and luminaires; levels for general lighting and for specific areas; analyses of seeing tasks; and other information essential to lighting the area and of value to lighting engineers and specialists, architects, construction people and others. Each practice is fully illustrated with charts and photographs.

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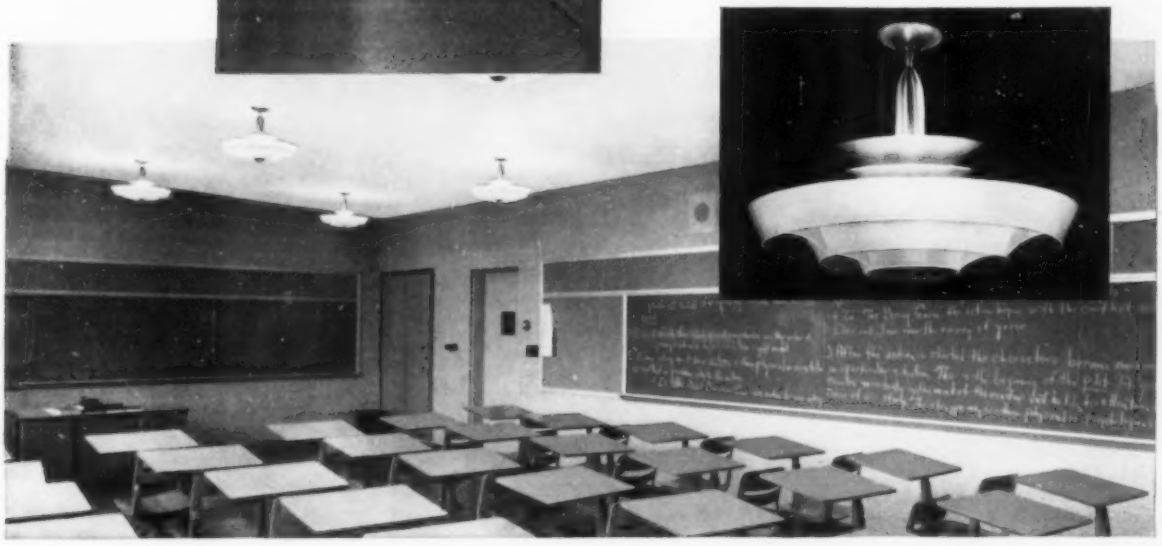

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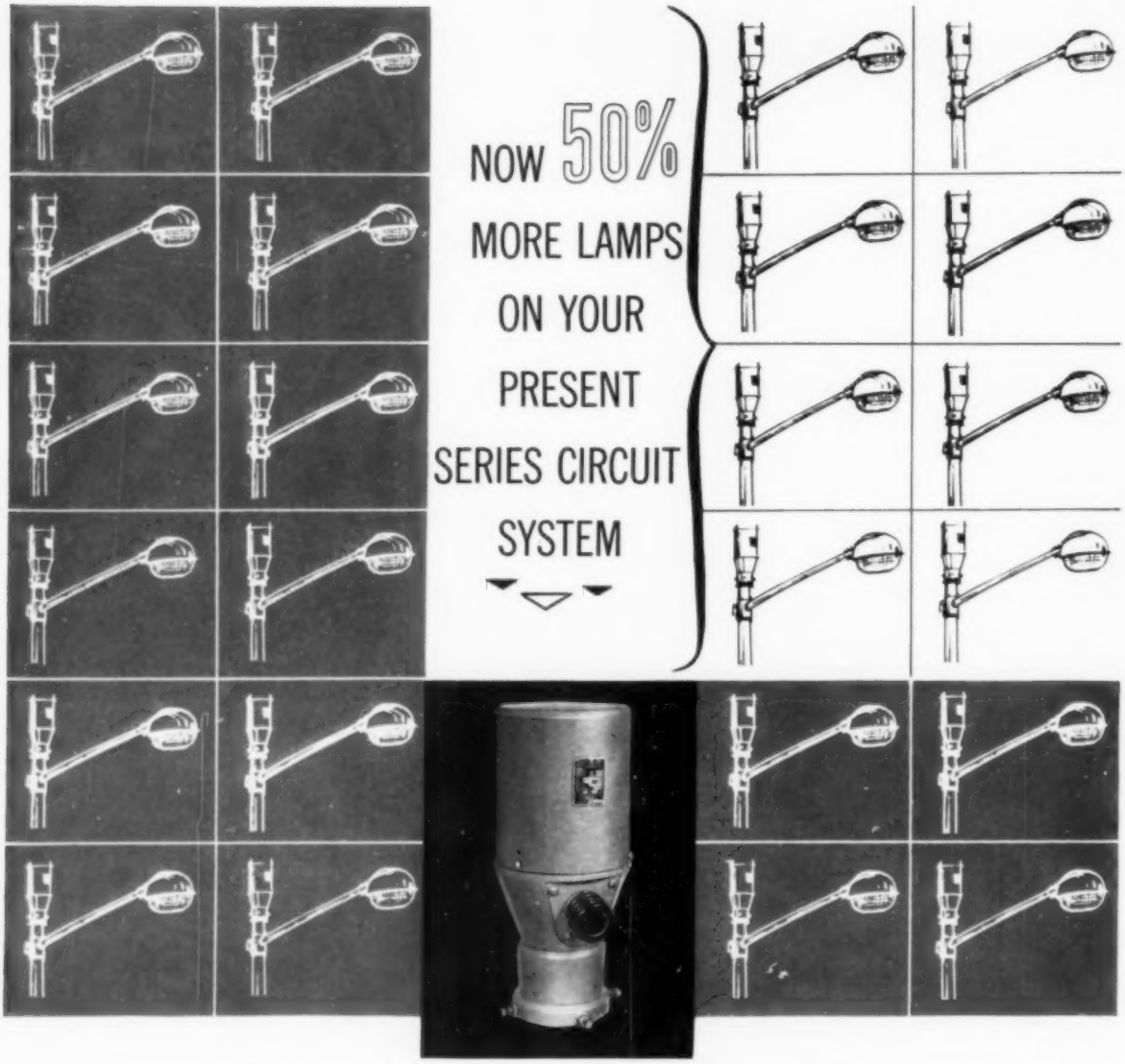

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Boston: Mass. Gas & Elec. Light Co.
Henry L. Wolfers Inc.
Fitchburg: Service Elec. Sup. Co.
Pittsfield: Carr Supply
Springfield: Eastern Elec. Sup.
Worcester: Atlantic Elec. Sup.
Benjamin Elec. Sup.
MICHIGAN
Detroit: Madison Elec. Co.
Michigan Chandelier Co.
Flint: Royalite Co.
Grand Rapids: Purchase Elec. Sup. Co.
Pontiac: Standard Elec. Co.
Saginaw: Standard Elec.
MINNESOTA
Duluth: Northern Elec. Sup. Co.
Minneapolis: Charles A. Anderson & Co.
Northland Elec. Sup. Co.
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MISSOURI
St. Louis: M. K. Clark
NEBRASKA
Omaha: Electric Fix. & Sup. Co.
NEVADA
Reno: Western Elec. Dists. Co.
NEW HAMPSHIRE
Portsmouth: Mass. Gas & Elec. Light Co.
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Youngstown: Mart Industries
OKLAHOMA
Tulsa: Lawson Elec. Co.
PENNSYLVANIA
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Erie: Kraus Elec. Co.
Harrisburg: Fluorescent Sup. Co.
Hazleton: Power Elec. Co. Inc.
New Castle: Midwestern Elec. Co.
Philadelphia: Ace Lighting Fix. Co.
Gold Seal Elec. Sup. Co.
Sylvan Elec. Fix. Co.
Pittsburgh: Allied Elec. Sup. Co.
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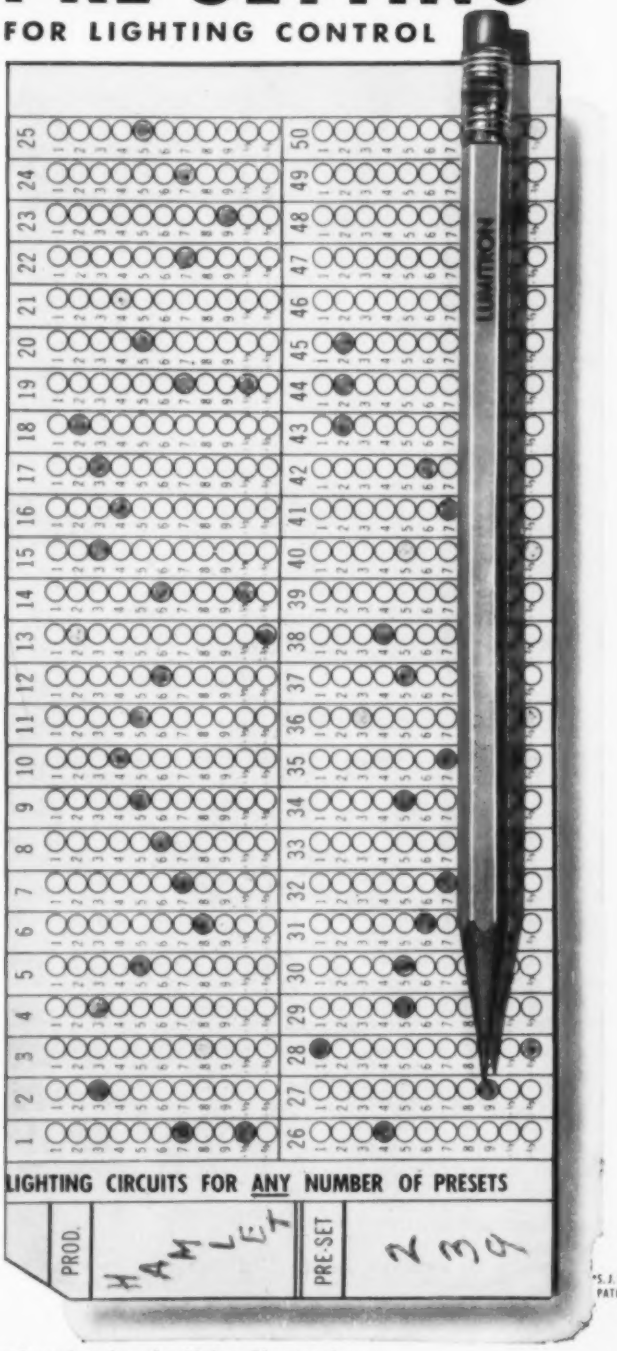

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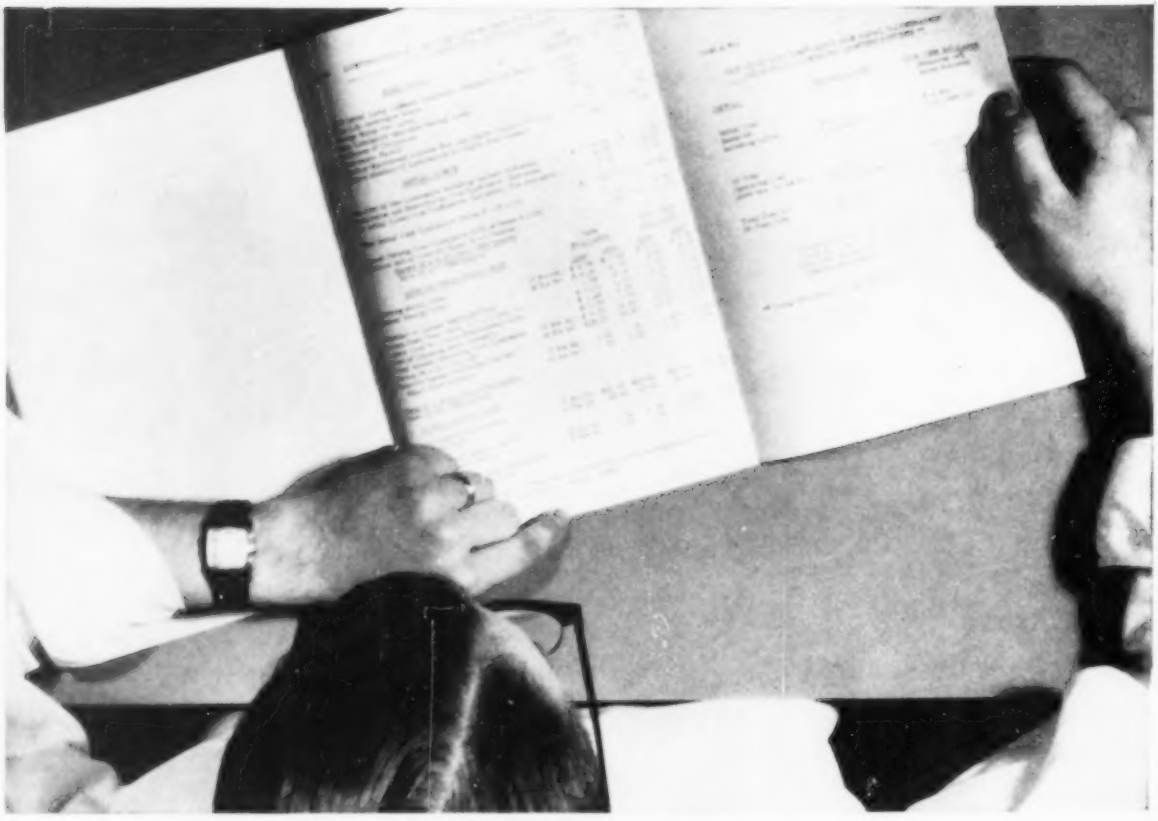

This report proves it costs many dollars more for the non-certified ballast you buy for a few nickels less

Certified Ballast Manufacturers, cooperating with lamp manufacturers, have set rigid standards for fluorescent ballast performance. A ballast that meets or exceeds minimum CBM specifications assures you rated lamp life and full light output, cool operation, reliable striking, and long ballast life. It carries a diamond-shaped CBM emblem. Without CBM specifications, there would be *no* standards for performance . . . no floor under quality.

Sola ballasts for general lighting applications meet or exceed CBM specifications or proposed specifications wherever they exist. Sola has no "secondary line" that does not meet the accepted minimum standards. Sola ballasts carry both the UL (Underwriters' Laboratories) emblem and the CBM emblem.

Other manufacturers are now making ballasts which are not designed to meet CBM standards. These ballasts bear only the UL emblem. In order to save a few cents, many people are using these ballasts, apparently under the impression that the UL emblem assures satisfactory lamp performance. *It does not.* UL performs valuable, but highly specialized tests, for *safety* only. UL does *not* test for operating characteristics that assure efficient, economical lamp performance and long lamp life.

We have prepared an engineering report analyzing the cost of lighting systems using non-certified ballasts as compared with systems using CBM certified ballasts. This report shows that while the initial cost of non-certified ballasts may be a *few cents* less, lighting systems incorporating them cost the user *many dollars more* in terms of reduced lumen output and reduced lamp life.

Write today for your copy of "An analysis of fluorescent lighting system costs as affected by ballast performance".

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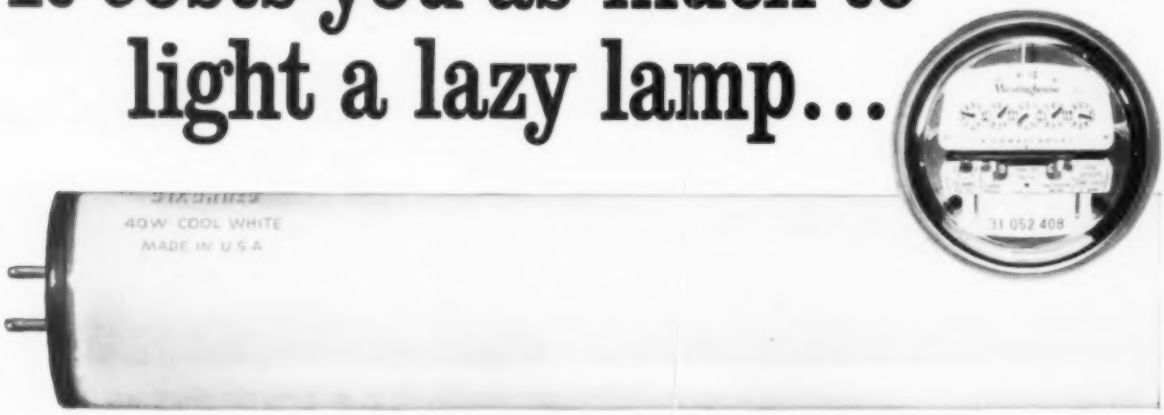
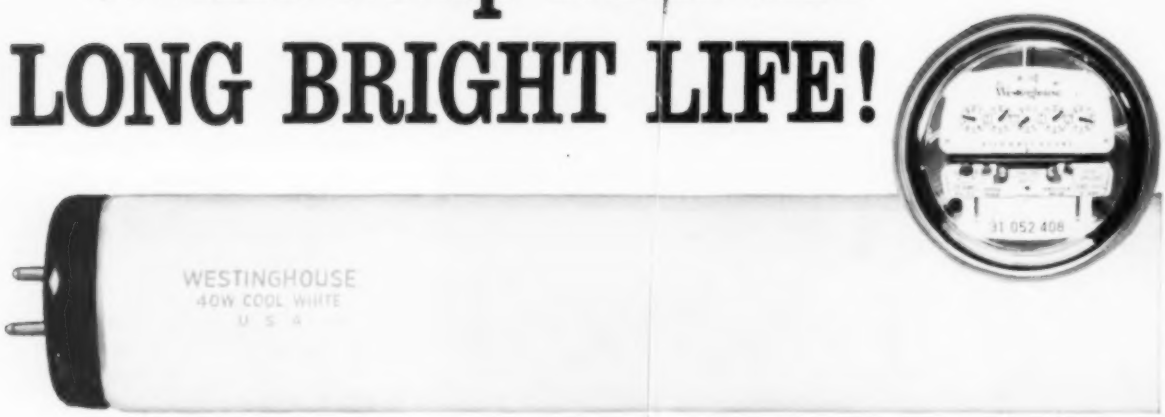


as a Westinghouse with "Ultralume" phosphors ...the lamp with the LONG BRIGHT LIFE!



SOME FLUORESCENT LAMPS get "lazy" fast. They eat up the same amount of electricity, but grow dimmer fast. Only Westinghouse fluorescents stay bright as new . . . longer, because Westinghouse lamps have "Ultralume"™ phosphors!

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Westinghouse (W) FLUORESCENT LAMPS

Corning Pattern No. 70 Low Brightness Lens Panels not only provide scientifically controlled illumination, they enhance the appearance of this inside office.

Demand *more* than just light from your lighting fixtures

You'll have a happy client when you get more than "just good light" from the lighting fixtures . . . when you give him fixtures that form an integral part of the overall design.

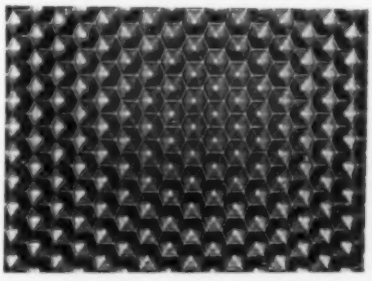
The office above is a typical example. Corning's Pattern No. 70 Low Brightness Lens Panels, flush-mounted in the ceiling, not only provide scientifically controlled light, but as design elements they blend with the ceiling both in shape and texture.

Made of crystal glass, these panels transmit a high intensity light that's free from glare. They do *not* distort color of the transmitted light. They provide a *pleasant* setting for a needed work area.

And with glass panels you can *assure* your clients that they'll *never* have to worry about warping, fading, discoloring. To keep them clean, just wipe with a damp cloth.

Whatever Corning lightingware glass you select, you get *more* than just light. You get a *basic* material formed into a component that *adds* to your design.

Facts on what glass to use, where, and why, are summed up in "Commercial Lighting Application Guide." Send for your free copy. See how to get *more* than just light from lighting fixtures.



Prisms built into the surface of Pattern No. 70 Panels control brightness in the critical zones, help provide high intensity light without glare. No color distortion of transmitted light, either. You can get pattern No. 70 in panels up to 34 inches wide, 100 inches long. Details in Bulletin L-110-A. Free.

Corning means research in Glass

CORNING GLASS WORKS 61-2 Crystal Street, Corning, N.Y.

(*Continued from page 23A*)

The first seven chapters are nearly the same in both texts, although the material has been rearranged. There are entirely new chapters dealing with calculus, differential equations, probability and electric-circuit theory. Problems are included after each chapter.

The author has been directly engaged, or closely associated with, the design of a wide variety of electric motors and generators for thirty years. He is now Consulting Engineer, Medium Induction Motor Department, General Electric Co., Schenectady, N. Y.

American Standard Definitions of Electrical Terms, C42, available from the American Standards Association, 70 East 45th St., New York 17, N. Y.

Nine volumes, of the sixteen planned by the sponsoring American Institute of Electrical Engineers, have now been published, totaling some 10,000 terms defined. The standards cover definitions for rotating machinery; switchgear; industrial control equipment; instruments, meters and meter testing; generation, transmission and distribution; electrochemistry and electrometallurgy; electron devices; electrobiology, including electrotherapeutics; mining.

American Drafting Standards Manual, compiled by Sectional Committee Y14 of the American Standards Association. Available from ASA, 70 East 45th St., New York 17, N. Y. Also available from the publisher, The American Society of Mechanical Engineers, 29 West 39th St., New York 18, N. Y.

Four sections of this manual have recently been published. These are: Y14.1-1957, Section 1—Size and Format; Y14.2-1957, Section 2—Line Conventions, Sectioning and Lettering; Y14.4-1957, Section 4—Pictorial Drawing; Y14.5-1957, Section 5— Dimensioning and Notes.

Sponsors of these standards are the American Society for Engineering Education and the American Society of Mechanical Engineers.

Practice of Consulting Engineering. Published by Engineers Joint Council, 29 West 39th St., New York, N. Y., $1.50.

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(*Continued on page 40A*)

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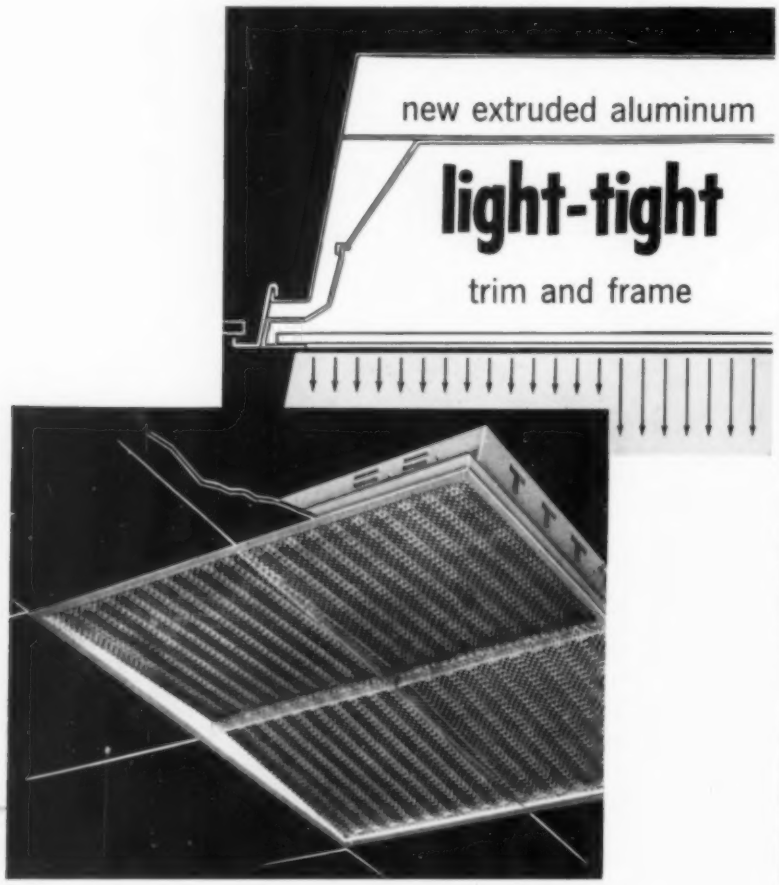

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(*Continued from page 38A*)

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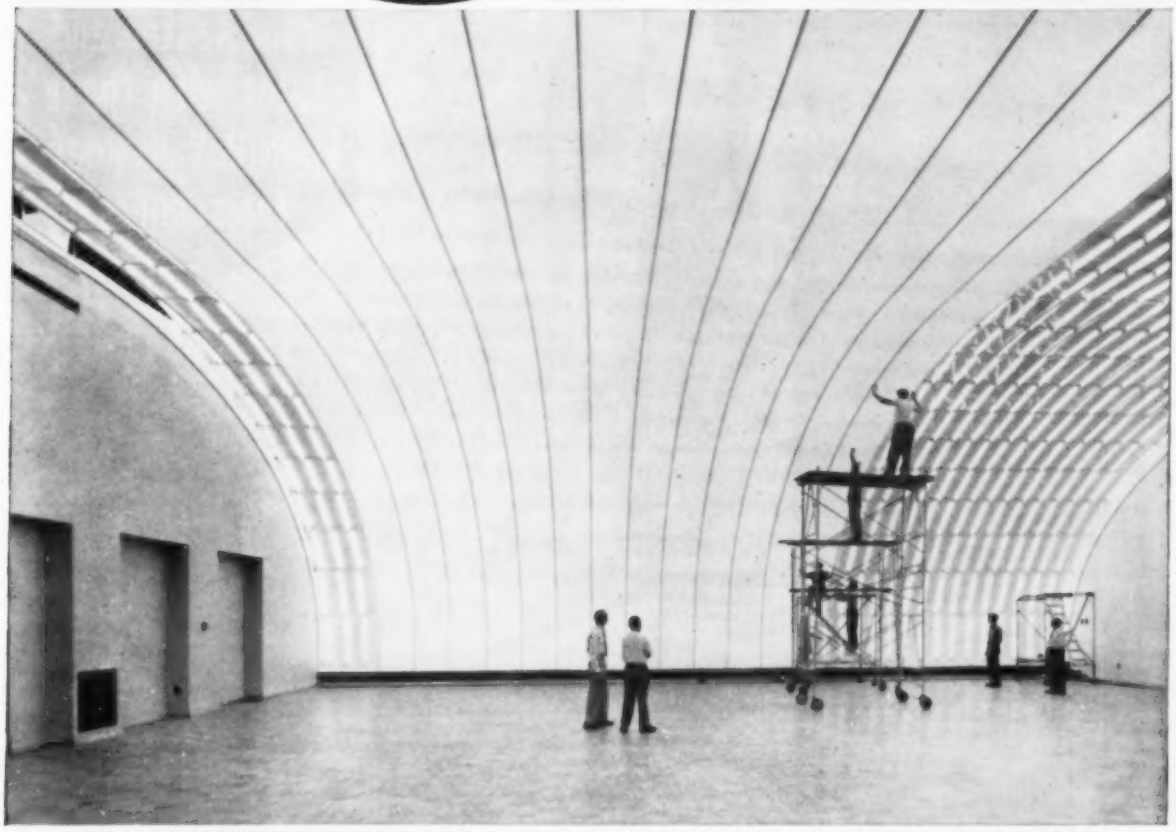
(*Continued on page 42A*)

LIGHT...



Light weight of BAKELITE Rigid Vinyl Sheet makes installation in this 21-foot high ceiling easy. Lamps are spaced 18-inches, and are alternately controlled to give 110 to 240 foot-candles at the working level 30 inches from the floor. Total lighting installation in this 110 x 75-foot room is 48 kw.

LIGHT... from the floor up

Chrysler Corporation built this styling room to give its designers the proper background for their new designs. To get the effect of an indoor sky, they used a luminous ceiling built from the floor up.

. . . and when The Wakefield Company picked the material to fit the job, they chose BAKELITE Rigid Vinyl Sheet. It's tough yet light in weight . . . easy to handle, easy to install.

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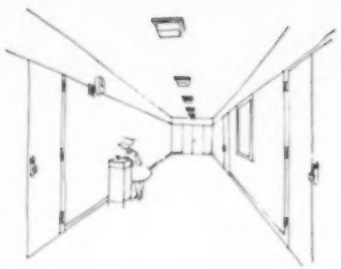
lighting design by mc Philben



Cast Aluminum Quality

mcPhilben's 32-88 square ceiling unit is U/L-approved for two 100 watt lamps. Its clean, modern lines, combined with maintenance-free operation, make it the ideal choice for institutions and industry: corridors, lobbies and lavatories.

The 32-88's face plate is of solid **cast aluminum** with a gleaming satin finish. Corrosion resisting construction features a reinforced and insulated back plate of zinc-clad bonderized steel. The cast carrara glass bowl swings to one side for easy cleaning. Available with mcPhilben's exclusive one-piece **cast aluminum** hinged guard. Also in vaportight 43-88 series.

Ask your nearby mcPhilben representative for full details. See our insert in Sweet's file 32a/mc or write for data sheet.

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LIGHTING COMPANY
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(*Continued from page 40A*)

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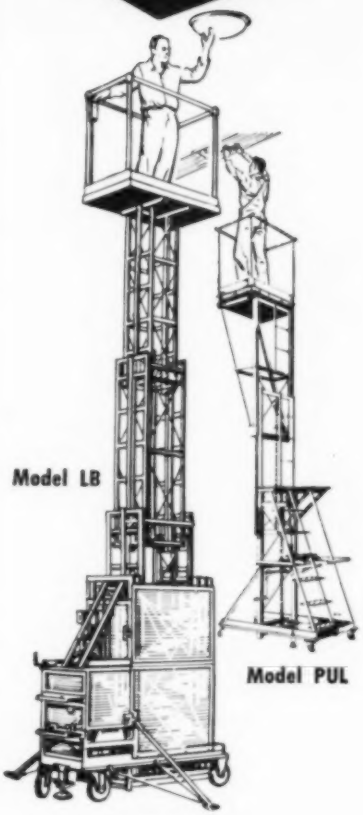

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(*Continued on page* 44A)

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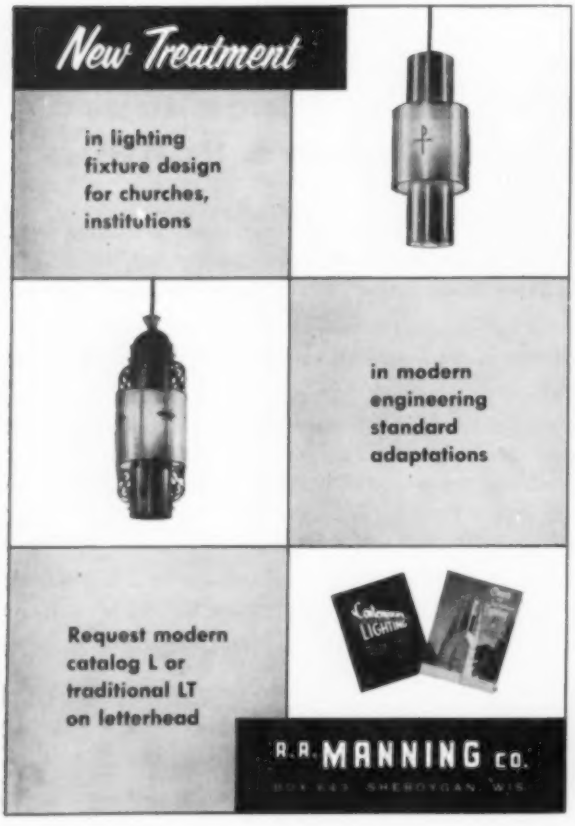
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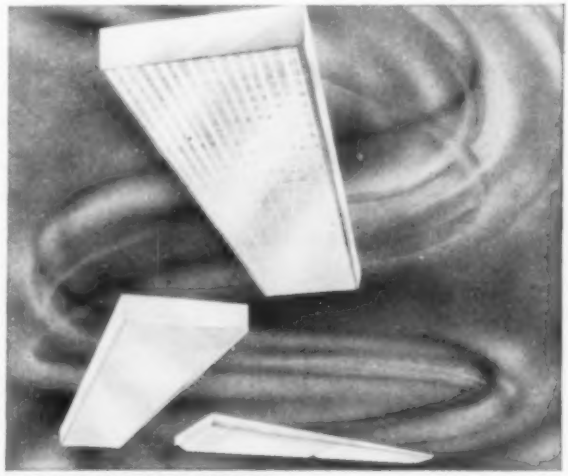

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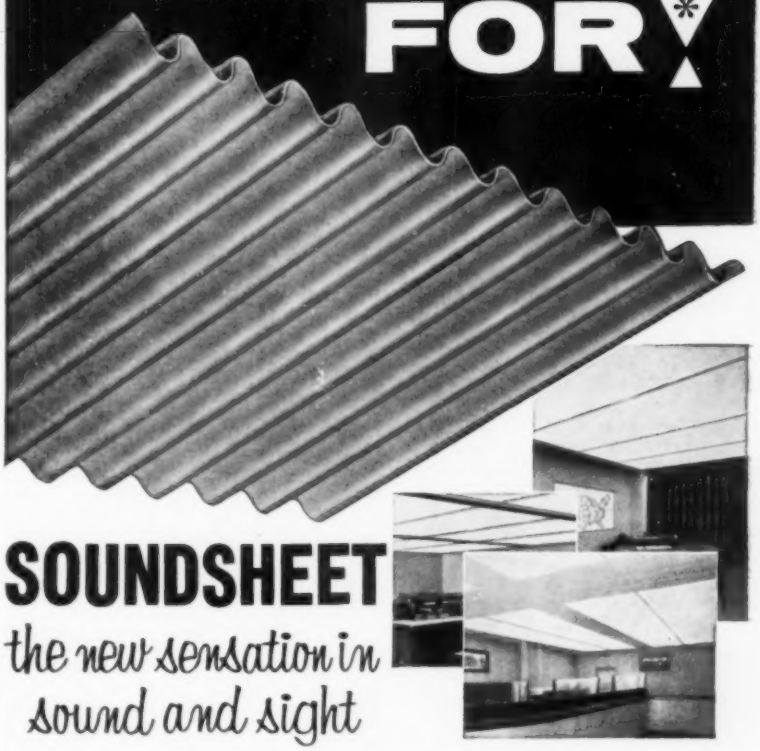

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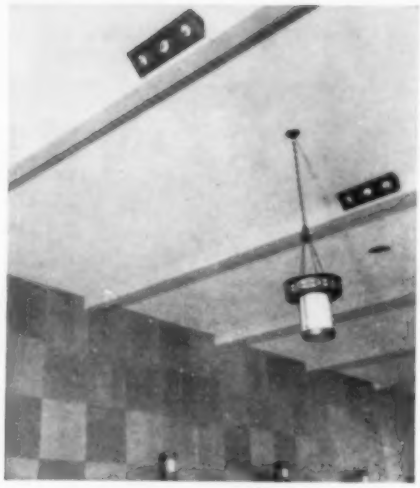

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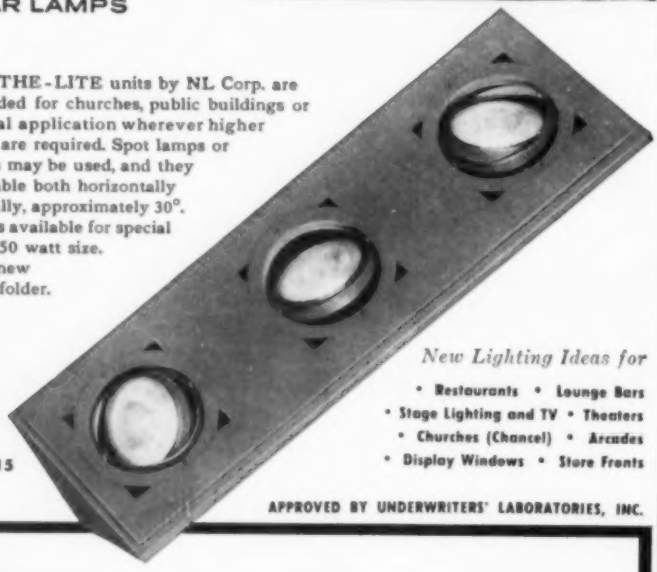

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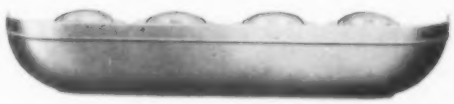

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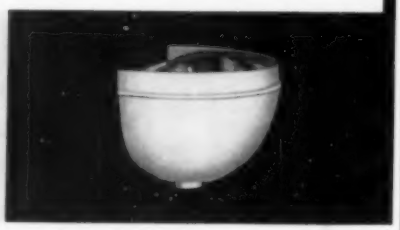

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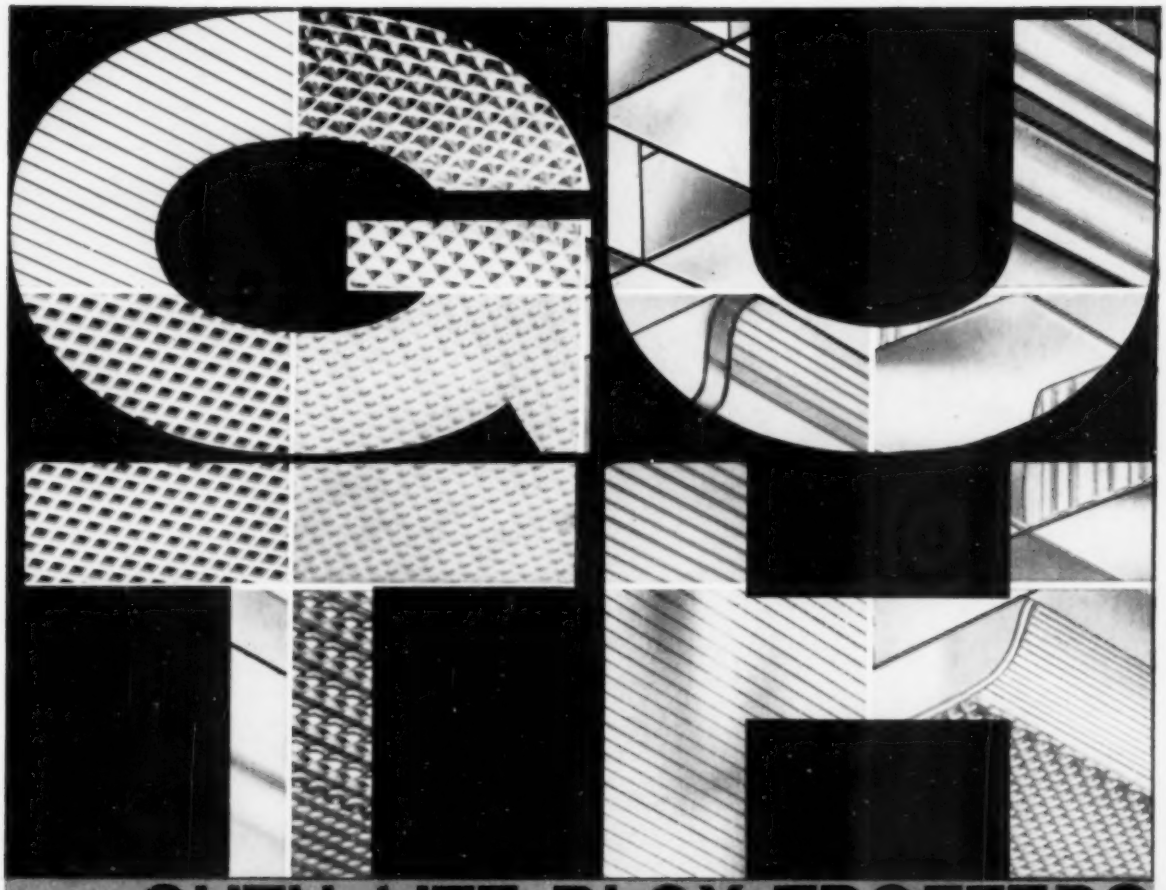

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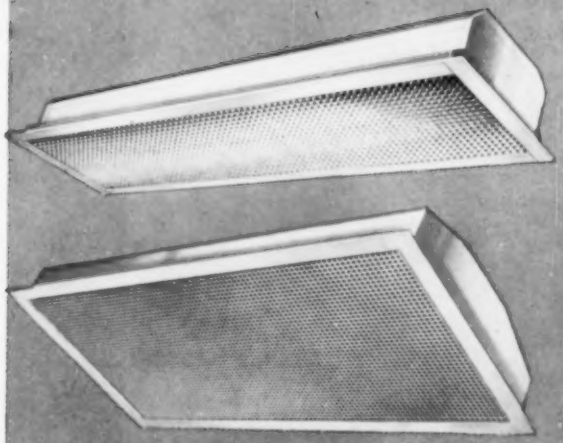

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